DIGEST OF INDUSTRIAL AND TECHNICAL DEVELOPMENTS

Tuition for Our Times

AFTER opening in Brussels, the great complex of events forming the European Congress of Chemical Engineering continued in Frankfurt linked with the German Exhibition called Achema. Among the exchanges of international courtesies and congratulations were some interesting ideas put forward by PROFESSOR EDY VELANDER, director of the Royal Swedish Academy of Engineering Sciences. Individuals are now compelled to specialise to acquire ever more profound knowledge in a steadily narrowing field. This emphasises the problem of communication for these vertical specialists often use languages which are less related than German, French and English. Hence the need arises of intellectual interpreters, of human catalyzers that can bring the minds together for fruitful cooperation and start a cross-fertilisation, essential for progress. In turn this leads to the conception of horizontal specialists, covering many fields of science such as mathematics, chemistry and physics, psychology and economics, all necessary for industrial development in such horizontal branches as instrumentation, regular technique, automatic control, optimisation through operational research and so on. Yet there is a possible difficulty, added DR. VELANDER, which could be summed up in the epigram "He is like a drop of oil on the water; the thinner it gets, the more it glitters with the colours of the rainbow."

This led the speaker to a better definition of an horizontal specialist. His knowledge must consist of narrow, but very high peaks, like an oscillogram of a train of high-tension impulses or a spectrogram of high resolution. He must know more advanced mathematics than most mathematicians do, but only in very narrow fields, he must know more physics on highly specialised subjects than most physicists and on so. Above all, he must have such common sense, tenderness and modesty as are necessary for the creation of efficient co-operation.

There are no courses for such horizontal specialists but they can get schooling of this kind from the combined colloquia and exhibitions which are now being organised in many centres.

What does Achema Mean?

APPARENTLY a disrespectful colleague of DR. BRETSCHNEIDER—the chairman of the Deutsche Gesellschaft für Chemisches Apparatewesen—has explained the meaning of the initials ACHEMA in a form which we can easily render into its English equivalent.

A ll is
CH aos
E nds
M ost
A ttractively

The definition might well apply to most exhibitions.

Can "Learning Machines" Control Industrial Plant?

A CONDITIONAL probability computer under development at the National Physical Laboratory appears to represent as great an advance on programmed computers as the latter on electro-mechanical calculators. From this type of "learning machine" it is hoped to develop an industrial control mechanism that will optimise its control function by a trial-and-error learning process. The computer also simulates certain features of animal learning. At the recent Open Day of the laboratory, there was a demonstration—deceptive in its apparent simplicity—of the computer controlling a device for following the boundary between a black and white area. The computer learns to modify its control function when a trolley moves from a region having black on the left to one having black on the right, and also when the steering linkage is reversed. It has five input channels labelled j, k, l, m, n and consists of 31 counter units which accumulate statistical information concerning the patterns of input activity presented in these channels. When some statistical data has been accumulated and when one or a group of the input channels is activated, the computer determines, on the basis of its stored statistical information, whether this group is usually accompanied by activity in another channel or channels. All this sounds very bewildering but PROFESSOR MACMILLAN of Swansea is studying its application to refinery control and DR. ANDREW of N.P.L. appears confident that although there will be greater complexity in using these principles for industrial control it does appear possible to make such applications.

Instrumenting a Pneumatic Transport Installation

NEW methods of measuring air and solid quantities in a pneumatic transport installation for aluminium oxide powder have recently been described by ING. L. BELOHLAVEK and ING. J. BRABLIK.* The solid is allowed to pass intermittently through a control valve into a reference bin from which it is pneumatically conveyed. Pressure readings are taken at four different points of the installation by bellows gauges of a type used in the aeronautical industry. Each of these is connected to the arm of a potentiometer in order to provide electrical signals, and the gas inlet is protected by a felt pad. Air flow is measured by orifice plate and the pressure difference telemetered from a differential manometer filled with mercury in which the mercury columns are made to act as potentiometer arms. The solid is metered by fitting a pressure gauge to a hydraulic cylinder supporting the reference bin. This is made to give a continuous indication of the weight in the bin. All instruments are fed with

an electrical supply from a signal generator with a stabilised output of 1 V at a frequency of 1000 c.p.s. All leads are connected to a 10-outlet unisiector and measurements taken at ½ sec. intervals so that a complete metering cycle takes 5 sec.

* *Strojirenstvi*, No. 4, 1958, p. 287.

Continuous Measuring of Strip Width

MANY industries may need to measure continuously the width of strip, but the heavy atmospheric pollution by scale dust near hot-rolling mills must present especially severe problems. In addition, the strip emerges at speeds of 400-600 ft/min. at a temperature of about 900°C. A non-contact method is most desirable to avoid interference with the free running of the strip. The method must also include allowance for lateral movement of the strip, which cannot be closely constrained in its guides.

The instrument developed by C. BURNS and J. W. STEVENS* to meet these exacting requirements is based on optical principles. The instrument operates by passing a parallel beam of light, suitably reflected, past both edges of the strip, so that opposite sides of the beam are shuttered by opposite edges of the strip. The residual width of the beam after passing by the two edges gives a measure of the variation in strip width. This measurement is made by shuttering a comparison beam from the same source so that its intensity balances the light intensity of the residual beam. The "measuring" and "comparison" beams are chopped at the source and the light from each falls alternately on a photocell, which generates an a.c. signal at the chopping frequency unless they are equal. The unbalanced signal is amplified and made to operate a servo-motor which drives a helical shutter to restrict the comparison beam until balance is achieved. Indication of width is secured by coupling the spindle of the shutter to a potentiometer which converts the reading of angular position into a voltage which operates a paper recorder with a high speed of response. An accuracy of 0.005 in. was obtained with a speed of response of 0.1 sec.

* *J. Iron and Steel Inst.* **189** Part 1, p. 60.

New Fluidised Bed Process at Appleby-Frodingham

THE contacting of solids by gases through the fluidising technique, whose principal ancestor is the Winkler process for brown coal gasification, is now a well established chemical engineering operation. New processes founded upon it such as fluidised sublimation for separating heat sensitive materials are continually arising; moreover, well established processes which have hitherto relied upon the fixed-bed method for gas-solid contact are also being recast in a fluidised form. So versatile is this technique that even tobacco has been "smoked" in a fluidised bed in order to produce nicotinic acid.

From Appleby-Frodingham comes news of an old process modernised by means of this new method but with the advantage over its predecessor of the ability to recover organically-bound sulphur. It is not altogether surprising that this Company, a branch of the United Steel Company, has long recognised the value of chemical engineering techniques in steelmaking and processes connected therewith. United Steel, in fact, already have experience of fluidised-bed technique through their manufacture of phthalic anhydride.

The plant developed by Appleby-Frodingham replaces the fixed bed/iron-oxide process still widely used for removing hydrogen sulphide from coke oven gas. Essentially it is a fluidised, hot-iron-oxide absorber plus regenerator. It enables the recovery of considerable quantities of sulphur as sulphuric acid and once started the process is self-supporting for its heat. Among its other advantages are a much speedier reaction time and the amount of spent oxide is a fifth of the consumption normally experienced in the conventional iron-oxide boxes. In compactness, fixed and operating costs the process should show appreciable economies over the established method.

For two years the pilot plant has been in successful operation purifying over 3 million cu. ft of coke oven gas a day. A full-scale plant scheduled for completion by the middle of 1959 will be able to handle 32 million cu. ft of coke oven gas a day. The Frodingham desulphurising process at an integrated steelworks making 1 million tons of steel ingots a year would allow as much as 250 tons a week of sulphuric acid to be produced. A number of details of this plant have yet to be revealed. Since iron oxide has a somewhat high density it will be interesting to know the exact conditions of fluidising since high gas rates would be expected to produce this condition. The exact method of making the process self sustaining in heat has also to be revealed, likewise the method of recovering solids and preventing erosion. The Company have appointed two licensees to build plants based on this process. They are Henry Balfour of Leven and W. J. Fraser of Romford.

Developments in Petroleum Refining

FROM 1952 onwards substantially all the emphasis in the oil industry has been on quality of petrol. This has been necessary to keep pace with the demands of the car industry. Compression ratios of internal combustion engines have increased significantly and there has been a parallel demand for increases in the Octane Number of petrol. Major process developments have been necessary to meet this demand, pointed out W. J. NEWBY in a recent paper to the Institute of Petroleum. This has included commercial introduction of catalytic reforming and its development into a key process for octane improvement. The introduction of this process has made available large quantities of hydrogen and a variety of versatile processes have been developed using catalytic reformer hydrogen for desulphurising or otherwise improving the quality of a wide range of petroleum products. Numerous new ways of gaining O.N. have been developed, mainly in the U.S.A. These, in conjunction with catalytic cracking, are suitable for stepwise installation for the production of petrols of the order of 100 research O.N. The various steps available include high-severity catalytic reforming, reformate splitting, alkylation, and isomerisation of light straight-run gasoline. For the production of the highest grades, the extraction of pure aromatics from reformates is envisaged. These developments are ideally suited for refineries designed for maximum output of petrol and in which catalytic cracking provides a substantial proportion of the high octane material. They are not wholly applicable to the situation existing in Western Europe because the ratio between petrol and fuel requirements is such that catalytic cracking must be kept to a minimum. In the lubricating oil field there has been application of the urea adduction process, the use of higher ketones for dewaxing, and the application of centrifugal extractors and rotating disk contactors for solvent treating. In the distillation field, progress continues in the design of vapour-liquid contact-

ing devices. Higher fractionating efficiencies, smaller tray spacings and smaller columns are being made possible by the use of perforated or sieve-type trays. Finally, MR. NEWBY referred to statistical mathematics and linear programming techniques which are finding a wide application in refinery operations. The application of computers to refinery programming and plant design is receiving increasing study.

All about Welding

WITHOUT welding, the peaceful application of atomic energy would have remained a physicist's dream. This is evidently why *Nuclear Power* has devoted an issue (May 1958) largely to a welding symposium introduced by DR. R. WECK, director of the British Welding Research Association. Manufacture of pressure vessels and heat exchangers is discussed by the engineers directly involved. Equally authoritative are the reviews dealing with aluminium, magnesium, rare metals and the heat-resisting steels. Contributors from the U.K.A.E.A. Industrial Group at Risley complete this sequence by describing current methods of non-destructive testing for nuclear plant. This is of special value since the interpretation of the radiographic evidence can perhaps lead to more argument than any other form of non-destructive examination. It is essential when making the assessment to be in a position to look at the actual welded joint so that surface marking can be correctly identified. Radiography is an expensive method of test, and full value should be obtained from the evidence presented.

Beneficent Bomb

APOLOGISTS for the heavy research expenditure which goes on under military auspices often point to the civilian crumbs which fall from the rich researchers' table. Some years ago, for example, there were rumours that Soviet workers on atomic weapons had blasted alternative routes for rivers draining into the Arctic. Dr. Willard F. Libby, member of the U.S. Atomic Energy Commission, has now provided his own illustrations for this theme. One of them is the "intriguing possibility" of shaking and breaking subterranean structures by nuclear shock. An underground detonation, of only 1.7 kiloton yield, is estimated to have crushed about 0.4 million tons of rock. It happened that the mountain selected consisted of rather soft rock, but nevertheless it was consolidated and supported its own weight. After the explosion, a sphere 260 feet in radius was crushed so that it could easily be mined. It was not rendered radioactive because the radioactivity was contained in thin rock shell which weighed only 700 tons. This was visually distinguishable from the ordinary rock and thus could be separated easily. Dr. Libby also referred to the containment of the heat generated from large atomic explosions in rock structures which are dry and therefore free of the pervasive thermal conductive characteristics of steam and water. This is thought to afford a definite possibility for generating atomic power if detonations which are large enough to make such power economical are practical and if the subsequent drilling and removal of the heat by injection of water to produce steam prove to be practical. Finally—and one may be forgiven for recalling the proverb about the steam hammer cracking a nut—there is the potential utilization of the radiation and heat of the bomb to cause chemical reactions. We are impressed but cannot help feeling that in many fields the crumb-fed civilian researchers could do with more of the loaf.

Letter to the Editor

The Hague,
17th April, 1958.

Dear Sir,

In the recent article by J. H. MCGUIRE in your columns[1] under the title "Fire Danger from Static Electricity," it is stated that further work is required on the aspect of making non-conducting liquids electrically conductive. Additives should be developed which would reduce resistivities to levels of the order of 10^{11} ohm cm. or less, so that charges would dissipate in a fraction of a second and would not build up.

I should like to bring to your attention that such a research programme has in fact been carried out by a team in the Royal Dutch Shell Group of Companies and that the results have just been published[2,3,4].

We set ourselves precisely the same goal of 10^{11} ohm cm. This was based on experimental evidence on electrification. The value was reached by means of a combination additive, the combination having proved far more effective than its individual components, the chromium salt of alkyl salicylic acid and the calcium salt of di-octyl sulpho succinic acid. As a consequence, an extremely small dosage in fluids of low viscosity, namely 2 kg of concentrated additive solution, containing 1% of each metal, on 1000 cu. m. of product proved sufficient for the purpose. The combination additive is added at an early stage in the manufacture of various petroleum products so that the products will be safe in all phases of handling, including the delivery to the customers. It could no doubt also find application in other industries dealing with fluids of similar electric conductivity.

The additive is being made on a technical scale and The Shell Group are already employing it in some products and intermediates and are collecting the necessary evidence to obtain authorities' clearance for the other products.

Yours faithfully,

A. Klinkenberg.

(N.V. DE BATAAFSCHE PETROLEUM MIJ.)

1 *British Chemical Engineering*, 1958, 3, 3, 136.

2 "Electristatics in the Petroleum Industry," a Royal Dutch/Shell Research and Development Report, edited by A. Klinkenberg and J. L. van der Minne (Elsevier Publishing Co. 1958).

3 "Laboratory and Plant Scale Experiments on the Generation and Prevention of Static Electricity," by A. Klinkenberg. Paper presented to 37 Annual Meeting of the American Petroleum Institute, Chicago, November 12, 1957, to appear in *Proc. A.P.I.* Division of Refining.

4 "Antistatic Additives in the Petroleum Industry," by A. Klinkenberg and B. V. Poulston. Paper presented before Institute of Petroleum, London, April 2, 1958, to appear *J. Inst. Petr.*

Differential Flotation of Lead-zinc Ores

THE most important factors influencing the flotation of lead-zinc ores are the degree of oxidation, the acidic or basic character of the gangue, the concentration of iron sulphides and the presence of copper ores. These are the most important conclusions of M. REY* in a recent paper suggesting a classification for these ores and their flotation techniques. For oxidised ores of galena-blende or galena-marmatite flotation can be carried out without or with very little depressant. Alkali is not normally necessary. If there is appreciable content of iron sulphide it leads to a rise in the alkali and depressant consumption and reduces the selectivity of the separation. Strongly acid oxidized ores must be washed or de-slimed. Otherwise an overall flotation is necessary followed by separation of the constituents in an alkaline circuit. For oxidized ores with a basic gangue the help of sodium sulphide or metallic zinc is needed to cause the blende to sink. If there is iron sulphide present, it is usually impossible to achieve a good recovery of lead. In

the presence of copper ores, combinations of cyanide with sodium sulphide or cyanide with sulphite or bisulphite have to be used to cause the blende to sink because the copper ions activate the blende.

* *Revue de l'Industrie Minerale*, Vol. 40 No. 1, 1958, p. 65.

Pitfalls in Patents

A PATENT case* has recently been considered by the House of Lords, on appeal from the Court of Appeal. The points brought out are of considerable interest. The owners of a group of patents in respect of ball-point pens and accessories for use with them issued a non-exclusive licence to another company entitling them to manufacture and sell the articles covered by the patents. Royalties were to be paid to the licensors on a sliding scale in which the percentage payments varied inversely as the selling price, excluding purchase tax, to the general public. The agreement contained *inter alia*, two clauses which required respectively that:

(1) The licensees should keep accounts of the patented articles sold and distributed by them and permit the licensors' auditors to examine the books to ascertain the amount of royalty payable. They were also required to give the auditors any other relevant information to enable them to ascertain the amount of royalty.

(2) That if the licensors subsequently issued a further licence with a lower royalty figure, that royalty figure should be substituted for the one in the original licence.

It was also laid down that the auditors could be required to give an undertaking of confidence if so required. The agreement could be determined in the event of a breach by either party, and it was ultimately determined. The events which led to the determination were:

(1) During one audit it was found that the licensees were selling three types of refill, A, B and C, of which type A only was covered by the patents and of which sales figures had been produced. The auditors requested detailed information about types B and C, to enable them to determine the amount of royalty payable. They were told that as these types were not covered by patent, they were not entitled to receive the information.

(2) The licensors issued a second licence to another company with royalties at a fixed rate which was lower than the maximum of the sliding scale, upon which the first licensees reduced the amount of royalty accordingly in respect of that part of the sliding scale.

The two points were argued in the lower court and the judge ruled that:

(1) The licensees were in breach of their agreement in refusing to give the extra information required.

(2) They were not entitled to the more favourable royalty by reason of the second licence.

The Court of Appeal reversed both decisions and there was a subsequent appeal to the House of Lords. The House of Lords allowed the appeal on the first count by a 3:2 majority and unanimously dismissed the appeal on the second. On the first count, the argument rested mainly on the wide field which an accountant's enquiries might cover if his view as to what constituted relevant information was accepted; and on the fact that an accountant was not necessarily competent to decide whether a certain article was covered by a patent. He might need to take advice and this action might be construed as a breach of confidence. As the goods concerned could be bought over the counter and were in regular use by the general public, it would not have been necessary to ask the firm for details in order to find out whether they were covered by a patent. Refills could have been bought and taken to a patent agent without mentioning the purpose of the enquiry. The majority opinion was that the licensees should have provided the information asked for. The second point was largely simple arithmetic. It was argued that if one royalty was at a fixed figure intermediate between points on a sliding scale it would be impossible to decide whether royalties could be reduced until the complete sales for a mutually agreed period, for both licensees, were available for comparison. The House of Lords took the view that on any article for which the second licence permitted a lower royalty, then the royalty under the first licence could be correspondingly reduced.

This case seems somewhat remote from the chemical industry, but if valves or pumps were subtituted for ball-point refills, the action would be much nearer home.

* Fomento (Sterling Area), Ltd. *v.* Selsdon Fountain Pen Co. Ltd All England Law Reports, 1958, Vol. 1, p 11

A 24-page reprint of a series of articles entitled "Liquid Atomisation in Chemical Engineering" by R. P. Fraser, O.B.E., M.I.Chem.E., P. Eisenklam, Ph.D., M.Eng.Sc., A.M.I.Chem.E., and N. Dombrowski, Ph.D., A.M.I.Chem.E., published in *British Chemical Engineering*, has been specially prepared in response to numerous requests. Copies are available from the Publishers at 4s. each, postage 2d. The appropriate remittance must accompany orders, which should be sent to The Circulation Manager, *British Chemical Engineering*, Drury House, Russell Street, London, W.C.2.

Hydraulics of a Turbo-Grid Tray

ALTHOUGH information has been published on the efficiency, throughput, cost and application of grid columns there remain important gaps in our knowledge. A recent paper by T. HOBLER and R. KRUPICZKA* presents fresh correlations based on the use of a 196-mm diameter column and restricted to the system air-water. This gives a number of equations for relations between the geometrical parameters and the flow rates. For example, the reduced height of water (excluding foam) measured from the top surface of the tray is given by

$$h_o = 1.85 \times 10^{-6} V_l^{0.4} V_g^{1.5} S^{-1.6}$$

where V_l is the liquid-flow rate and V_g the gas-flow rate both in cubic metres per second. Using dimensionless groups, the data have been related to a modified EULER number by the equation

$$\mathrm{Eu} = 2.5 \times 10^{-4} \cdot \mathrm{Re}_l^{-0.6} \mathrm{Re}_g^{0.5} \left(\frac{L}{S}\right)^{1.5}$$

In this, the subscripts l and g refer to liquid and gas respectively, while L is the length of a slot and S the width. After acknowledging the limitations of this work, the authors suggest a procedure for using the correlations for design. Such parameters as surface tension, density and viscosity of the fluids were excluded from the investigation; so also were the effects of pressure and of depth of slot. Nevertheless, this represents a considerable contribution to published information in a relatively new field.

* *Chemia Stosowana.* 1 No. 2, p. 105.

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British Chemical Engineering
A HEYWOOD PUBLICATION

The Metric System for Britain?

THE appearance at the Chemical and Petroleum Engineering Exhibition at Olympia of equipment dimensioned in metric units and the presence in the current issue of this journal of worked examples employing the same units are reminders of the existence of two widely-used systems which sooner or later will have to be reconciled.

The problem the existence of the two systems places before British equipment manufacturers springs from the fact that as an exporting country we have to send the products of our industries to inch/pound as well as to metric system areas, and, although we have well-established and expanding markets in the English-unit countries including the U.S.A., Canada and most of the Commonwealth countries, among the users of the metric system vast potential markets including such newly developing areas as India and China are to be found. Moreover, the imminence of the European free trade zone adds urgency to the problem, and makes necessary a review of the advantages and disadvantages of the metric system.

Since its evolution in France at the end of the eighteenth century, many attempts have been made to introduce the metric system into this country. If these attempts have sometimes been half-hearted, the resistance to acceptance of the metric system seems at all times to have been uniformly tough; this, perhaps, because it has emanated from commercial sources led more easily by tradition and even prejudice than by a balanced view of the pros and cons. The Hodgson Report, first published in 1951, surveyed in great detail the difficulties of the English system and underlined the complications of the apothecaries' troy and pennyweight systems. It pointed out deficiencies in the Imperial standards for length and urged agreement between Britain and America on a redefined and equal inch, accurately related to the metre. More recently, the Federation of British Industries, the Association of British Chambers of Commerce and the British Association have formed committees to examine afresh this subject and to make further recommendations. It will be recalled that the Hodgson report recommended that this country, in concert with the Commonwealth and the U.S.A., should abolish the British system in favour of the metric system over a transition period lasting about twenty years. The interest which the subject has awakened among the engineering community is reflected in a recent conference organised jointly by the British Standards Institution and the Institution of Production Engineers, when H. G. Conway gave a résumé of arguments for and against the metric system.

In its favour are its decimal character and therefore its easy subdivision; its convenience to engineers—especially those concerned with close tolerances; the fact that the inch by comparison is too large a unit and, above all, the system is an international one of wide and expanding usage —it has recently been adopted by India—so that today a greater part of the earth's population employs it. To its disadvantage is a liability to error through the decimal point—not a powerful objection unless educational standards are to decline rather than rise. That few people are familiar with it is another shortcoming, for while most schoolboys with a knowledge of science will know about the c.g.s. system, the population as a whole will have no knowledge of it. This is a problem of transition, and does not reflect any inherent weakness in the system itself.

Some of the arguments for not adopting the system take the line of stressing the inconvenience in ordinary everyday life the use of the system would cause. Others are concerned that its use may lead to gross incongruities. We are invited by these protagonists of the English system to imagine the situation at the "local" where instead of ordering a half-pint of bitter we have to ask for 0.568 litre; or its allegedly unpractical side might be illustrated by the example of a car park attendant who exhorts a customer to back not just another inch but another 25.4 millimetres. Within these apparently frivolous arguments is the kernel of a protest not so much against the metric system itself, but against its rigid application, but this is something which even its most ardent champions would eschew, for they recognise that the halves, quarters and thirds of the English system must inevitably be retained. But in their proposal to reject the eighths, the abominable thirty-seconds and the accursed sixty-fourths there is much wisdom. But the greatest stumbling block is the high cost to British industry of its adoption—H. G. Conway quotes a cost range of £50 million to £200 million or more—and the organisational effort required to make the change.

In this country, the chemical engineer in the chemical industry is normally compelled to work with parts of both systems and this, to him, is no more than a minor problem. Results of research work and basic data are generally reported in c.g.s. units and some of his calculations may be carried out with metre-kilogram-second units or even metre-tonne-second units; again, a great deal of continental chemical engineering work is reported in some or other variant of the metric system. The English system of units, however, is still widely used for most industrial and engineering quantities; as a consequence, the chemical engineer finds himself working in both systems. The signs are that the chemical industry is in advance of most others in its use of metric units for its basic engineering. For although most of its engineering drawing may use the British system, the use of the metric alternative on the production side is well established at many plants and may be expected to grow. This perhaps presages the eventual acceptance of the system, for with its advantages, even though they be marginal, powerful evolutionary factors in the world press for its adoption. Since the cost of the change is so clearly prohibitive to industry, the expense must be borne by the nation as a whole, and the government of the day must take upon itself the task of meeting the cost and of bringing about the change. As the recent conference showed, and as the bodies now considering the matter will most certainly show when their conclusions are published, neither good advice nor goodwill will be lacking.

66.096.5

FLUIDISING PLANT AND ITS DESIGN

The author presents a new design method, based upon a simple experimental test on a sample of particles and upon a novel definition of particle characteristics

by Ing. J. BERANEK

INDUSTRY is paying ever-increasing attention to the characteristics of the fluidised bed. Data on which to base calculations of the fundamental characteristics of the fluidising plant, such as the dimensions for a given throughput, the flow of gas for a given size of the particles, expansion of the bed and the pressure drop, can be generally found in the literature. Since, however, the available data varies to a considerable degree, to avoid confusion a new method of obtaining design information has been evolved.

Theoretical Part

The particles present in a fluidised bed are generally described by their diameter and the shape factor. The shape factor is affected by both the shape and the size of the particle, and its dependence on the latter is a function of the character of the stream of the fluid passing the particle. It can be proved[1] that the behaviour of a particle in the fluid can be described by:

$$\varphi\,(\mathrm{Ar}, \Omega, \Pi_1, \Pi_2, \ldots) = 0 \qquad \ldots(1)$$

where $\mathrm{Ar} = \dfrac{Z_s}{\rho_f v^2}$ — Archimedes' criterion;

$\Omega = \dfrac{v^3 g\ \rho_f}{g\ v\ \rho_z}$ — new criterion of similarity;

$\Pi_1, \Pi_2, \ldots$ — criteria describing the flow of the fluid and the geometry of the plant.

Criteria Ar and Ω describe any system of particles in a fluid regardless of whether it is in a fluidised bed, pneumatic transport, separation in cyclones, sedimentation, etc., as long as there is a dynamic balance between the particles and the fluid in the system, i.e., the equilibrium of the forces acting upon the particles. These forces are the gravitational and the centrifugal forces on one hand and the forces arising from the presence of the fluid on the other. The physical parameters contained in the criteria Ar and Ω are so devised that the linear dimensions of the particle are excluded.

Equation (1) becomes:

$$\varphi_1\,(\mathrm{Ar}, \Omega) = 0 \qquad \ldots(2)$$

for a particle travelling in an infinite space filled with a static fluid. This equation defines the basic properties of the system of particles in the fluid. Thus the characteristic parameters of a particle are its terminal velocity v_o and its apparent weight (the weight minus the buoyancy). The numerical values of these parameters are easy to find. To obtain numerical values for particles of a definite shape from Equation (2) the results of measurements carried out by E. S. PETTYJOHN and E. B. CHRISTIANSEN were used.[2]

Ing. J. Beranek *is a chemical engineer at the Institute of Organic Synthesis in Pardubice-Rybitvi, Czechoslovakia*

Used Symbols

$\mathrm{Ar} = \dfrac{Z_s}{\rho_f v^2}$ = Archimedes' criterion;
d_s (m or mm) = diameter of the particle;
g (m/sec²) = gravitation;
h_o or h (m) = height of unexpanded or expanded bed;
$m_1\ \triangle m$ (kg) = weight of particles;
u (m/sec) = fluid velocity (relative empty vessel);
u_o, u_v (m/sec) = fluid velocity at the point of incipient fluidisation or particles transport;
v_o (m/sec) = terminal velocity of the particle;
Z_s (kg) = apparent weight of the particle (minus buoyancy);
ϵ_o or ϵ = voidage of bed;
v (m²/sec) = kinematic viscosity of the fluid;
ρ_f or ρ_s (kgm⁴/sec²) = reference mass of the fluid or particle;
$\rho_z = \rho_s - \rho_f$ = apparent reference mass of the particle;
Π = criteria of similarity of the fluid in motion and geometric similarity; and
$\Omega = \dfrac{v g^3\ \rho_f}{g\ v\ \rho_z}$ = new criterion of similarity, which together with Archimedes' number (Ar) describes the behaviour of particles in a fluid.

Similarly, the results of the author's own measurements were used in the case of particles of crushed substances. The results of the measurements are shown in Fig. 1.

The measurements show that the characteristics of the particles with no predominant dimensions such as the particles of crushed substances are similar to those of tetrahedrons. The flat or needle-like particles show smaller values of Ω for the same identical value of Ar. Exact knowledge of all parameters of Equation (2) is important, because it enables theoretical investigations of the behaviour of the particles to be carried out in conditions impossible to simulate in the laboratory. This would apply to processes requiring very high temperatures, or involving substances injurious to human health.

Often a mixture of particles of different sizes is handled. The mixture is best described by the characteristics (Ω) of its average particle, which also will be used as the basis for the construction of the required graph. The value of the criterion Ω of the average particle is found with the aid of the instrument shown in Fig. 2 in the following way. The lower part (A) of the instrument is filled with a known quantity of particles and air is allowed to blow at them. The air flow is so adjusted as to blow away only a small quantity of the particles, and it is cut off when no

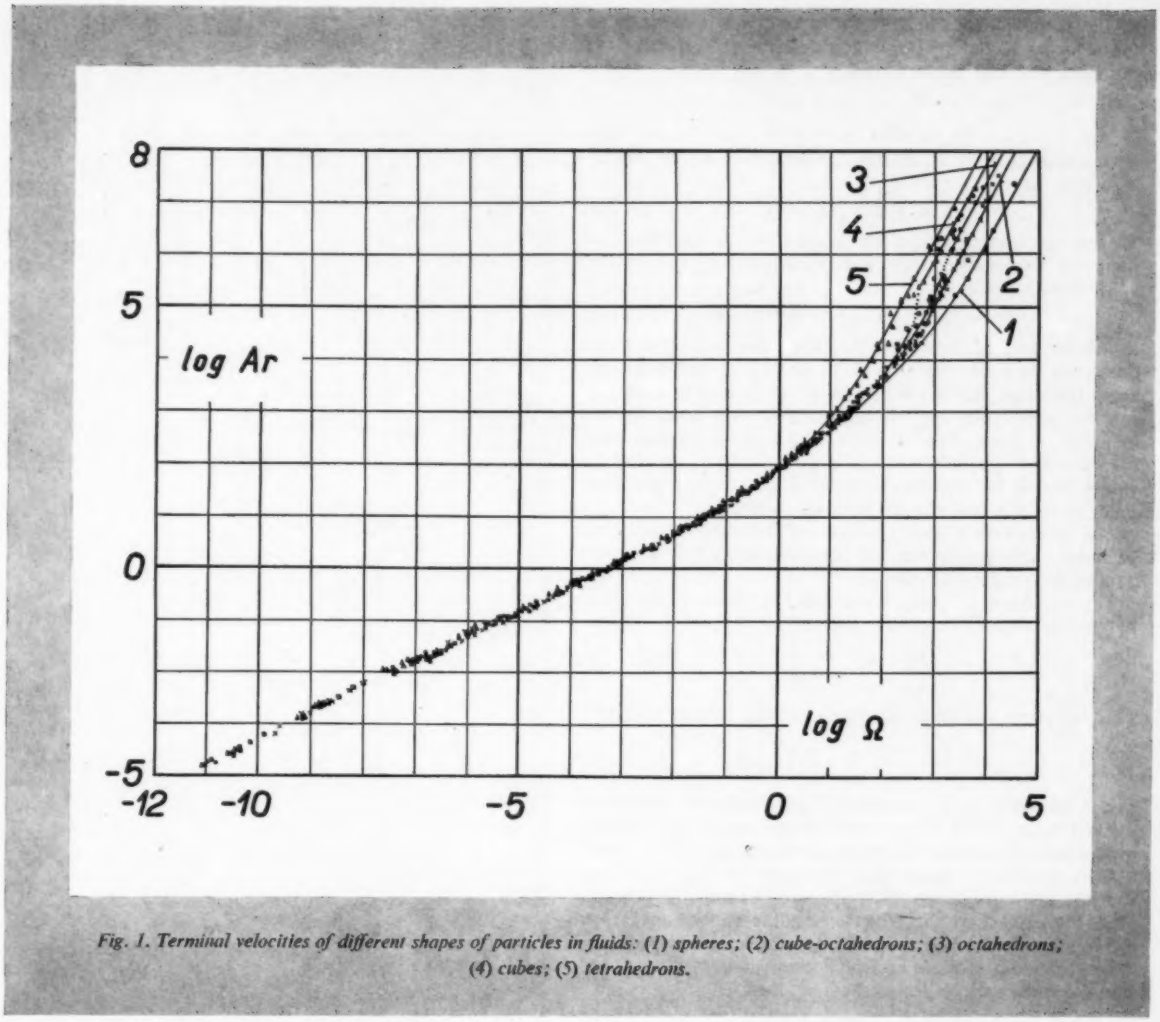

Fig. 1. Terminal velocities of different shapes of particles in fluids: (1) spheres; (2) cube-octahedrons; (3) octahedrons; (4) cubes; (5) tetrahedrons.

more particles are being blown away. The weight of the remaining particles and the previous air velocity are plotted in Fig. 3. The process is repeated by increasing the air speed stepwise until all particles are gone. The complete curve of Fig. 3 is thus obtained. The first derivation of this curve gives the most frequent size of particles present in the mixture, and will be referred to as the Incidence Curve. The maximum of Incidence Curve coincides with the point of inflexion of the original curve. The position of the inflexion point can be easily found, and the Incidence Curve need not then be drawn. The apparent weight Z_s is made equal to the weight of the average particle. It is obtained by dividing the weight of a certain number of them (usually 100) by their number. From this information the criteria Ar and Ω can be calculated and the graph of Fig. 1 constructed. In the case of very fine particles, which cannot be easily measured and counted, it is possible to obtain the necessary information by interpolation with a straight line sloping at 30 degrees. This method is recommended for $\Omega < 10^{-2}$.

Inspection of Fig. 1 reveals the similarity between Ω and Reynolds number. It can be said, therefore, that where $\Omega < 10^{-2}$ the flow falls in the laminar region and when $\Omega > 10^{-3}$ the flow becomes turbulent. In the laminar region the validity of the graph is limited through the Brownian movement, which can become important where $\Omega < 10^{-20}$. Fluidisation of particles of this size is outside this consideration. In the turbulent region the slope of the interpolating straight line in the graph is approximately 70 degrees, and is constant for all velocities up to the speed of sound in the liquid. The validity of the graph could be extended if a further parameter, the Mach number, was introduced. This region is so far beyond practical exploitation. In practice the measurements are therefore limited to the cases where $10^{-2} < \Omega < 10^{5}$.

Porous particles are frequently used in industry. Here a certain ambiguity can be created by two different interpretations of the apparent mass $\rho_z = \rho_s - \rho_f$ contained in the definition of the criterion Ω. Let us therefore designate the porosity of the particles ε_s and the actual specific weight of its solid part ρ_s. Substitution of the term $\varepsilon_s \rho_s$ will make the lines of compact and porous particles merge into a single line (see Fig. 1). If, however, only ρ_s is substituted the separation between the lines will increase as the porosity of the particles increases. The second method seems to offer a considerable advantage in characterising the catalyst because of the ease with which the porosity can be described.

Fluidised Bed

The experiments with fluidisation show that the expansion of the fluidised bed is independent of the dimensions

of the plant and the height of the bed, but it depends on the velocity. Equation (1), which describes the state of the fluidised bed, can be re-written:

$$\varphi_2 (\mathrm{Ar}, \Omega, u/v_g) = 0 \qquad \ldots.(3)$$

$$\text{or } \varphi_2' (\mathrm{Ar}, \Omega, \varepsilon) = 0 \qquad \ldots.(3a)$$

By comparing both equations the definition of the expansion becomes:

$$\varepsilon = f\ (\mathrm{Ar}, \Omega, u/v_g) \qquad \ldots.(4)$$

This expression describes the conditions at the point of incipient fluidisation very well and leads to the critical velocity expression

$$u_o/v_g = f\ (\mathrm{Ar}, \Omega, \varepsilon_o) = 0.045\,\varepsilon_o\,\Omega^{0.2} \qquad \ldots.(5$$

It will be noticed, however, that the numerical evaluation does not include the criterion Ar. It is therefore an approximation; the error involved in its use is small as can be seen from Fig. 4, and can be neglected in the majority of cases. Theoretical considerations indicate that the difference probably equals a power of ϵ_o and that its values would be different according to whether the flow belongs to the laminar or turbulent region.

The calculation of the expansion of the fluidised bed may be more conveniently carried out from equations not containing the criteria Ar and Ω.

This can be done using Equations (3), (3a) and (5) which define the expansion of the bed as:

$$f'\left(\frac{u}{v_g}, \frac{u_o}{v_g}, \varepsilon, \varepsilon_o\right) = 0 \qquad \ldots.(6)$$

This equation can be developed one step further to give:

$$f'\left(\frac{\varepsilon-\varepsilon_o}{1-\varepsilon_o}, \frac{u-u_o}{v_g-u_o}\right) = 0 \qquad \ldots.(7)$$

Fig. 5 is based on the results of measurements published by WILHELM and KWAUK,[3] and on the results of original measurement carried out by the authors. It will be noted that the function is linear up to the value $(u-u_o)/(v_g-u_o) = 0.45$. The curvature which appears beyond this point is probably caused by the effect which the walls exercise on the moving fluid when the porosity ε approaches unity.

In practice it is more convenient to calculate the expansion from the ratio h_o/h, so that:

$$f''\left(h_o/h, \frac{u-u_o}{v_g-u_o}\right) = 0 \qquad \ldots.(8)$$

Graphical representation of this equation is given in Fig. 6, which shows, together with Fig. 5, that the particles begin to be blown away when either

$$\frac{u-u_o}{v_g-u_o} = 1 \quad \text{or} \quad \frac{u}{v_g} = 1 \qquad \ldots.(9)$$

By means of the foregoing data, it is possible to design a fluidising plant, and some worked examples follow.

The definitions given in this article do not apply to the layers containing large bubbles or pistons of the fluid. In such cases the height of the bed and the size of the plant control the dynamic conditions. Equations (3) and (3a) do not contain characteristic criteria of the fluid layer of this kind and their validity is therefore limited only to practical cases. When the particles in the bed vary considerably in size the results obtained from the formulæ discussed above will lose their accuracy. This will become evident mainly in the expansion of beds which have the tendency to grade the particles according to their size. Batch fluidisation of the whole bed of solids cannot be realised when $u_o > v_{g\ mm}$, because at the terminal velocity the smaller particles are gradually blown away. This is not true, however, of beds in which the fluid is formed of minute bubbles, for then a certain percentage of small particles remain in the layer. This case has not yet been studied by the authors.

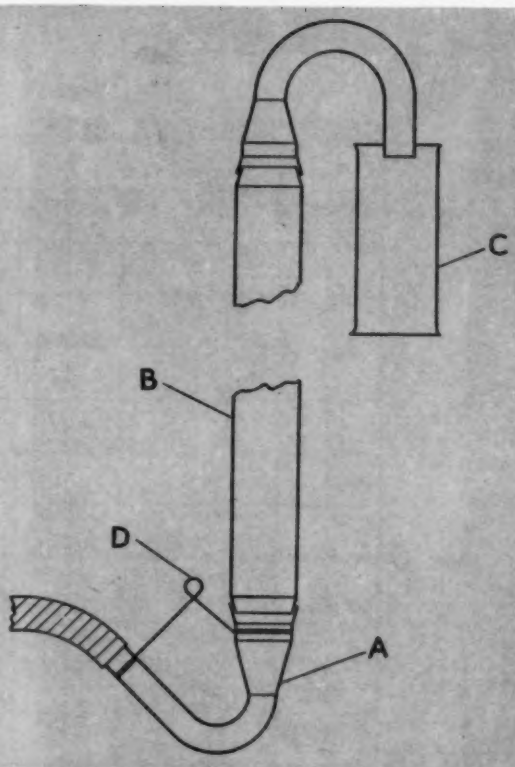

Fig. 2. Instrument for measuring the characteristic of the particles: (a) reservoir of the particles fitted with an air-inlet; (b) analysis pipe, 25 mm diameter and 2.5 m long; (c) cylinder for collecting the blown-away particles; (d) holder supporting the bend.

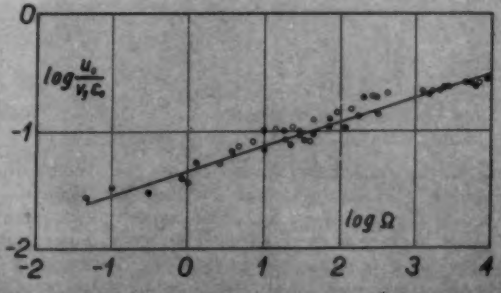

Fig. 3. Results of fluidising test on the silica-gel particles, size range 0.43-0.47 mm.

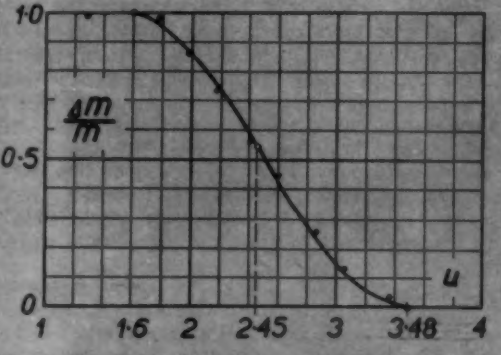

Fig. 4. Graph for determining critical velocity at the threshold of fluidisation.

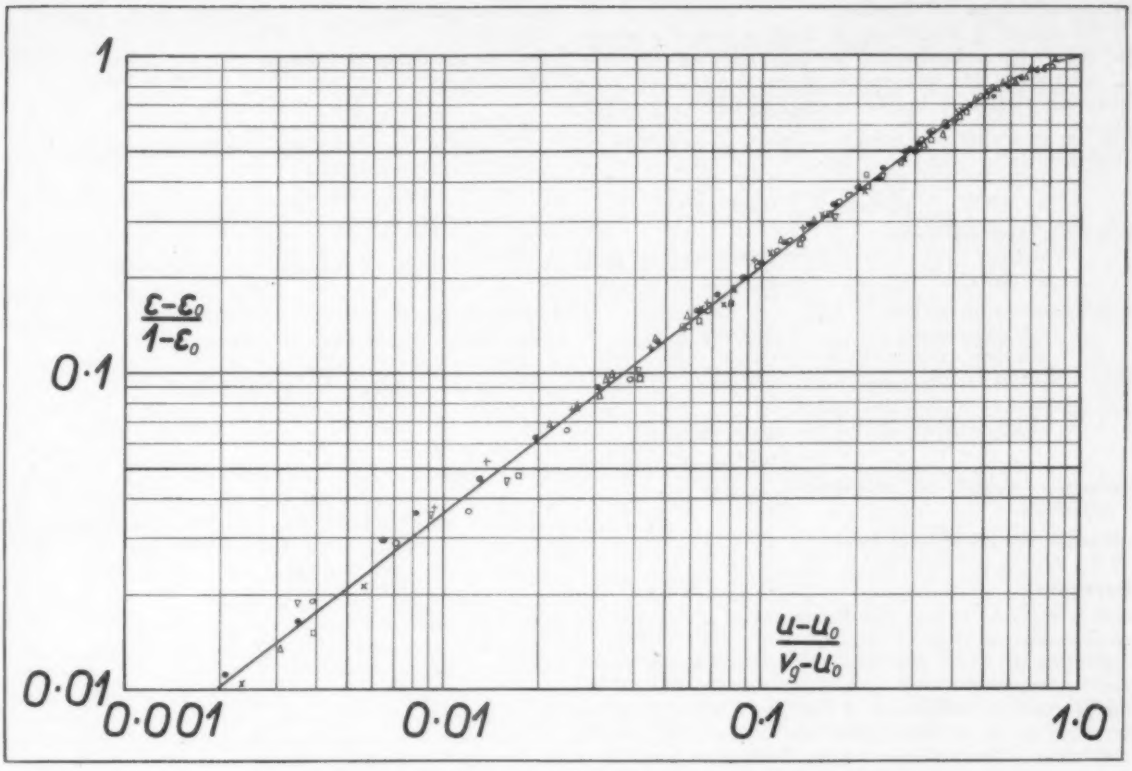

Fig. 5. Expansion of fluid bed with porosity expressed by $\varepsilon-\varepsilon_0/-\varepsilon_0$.

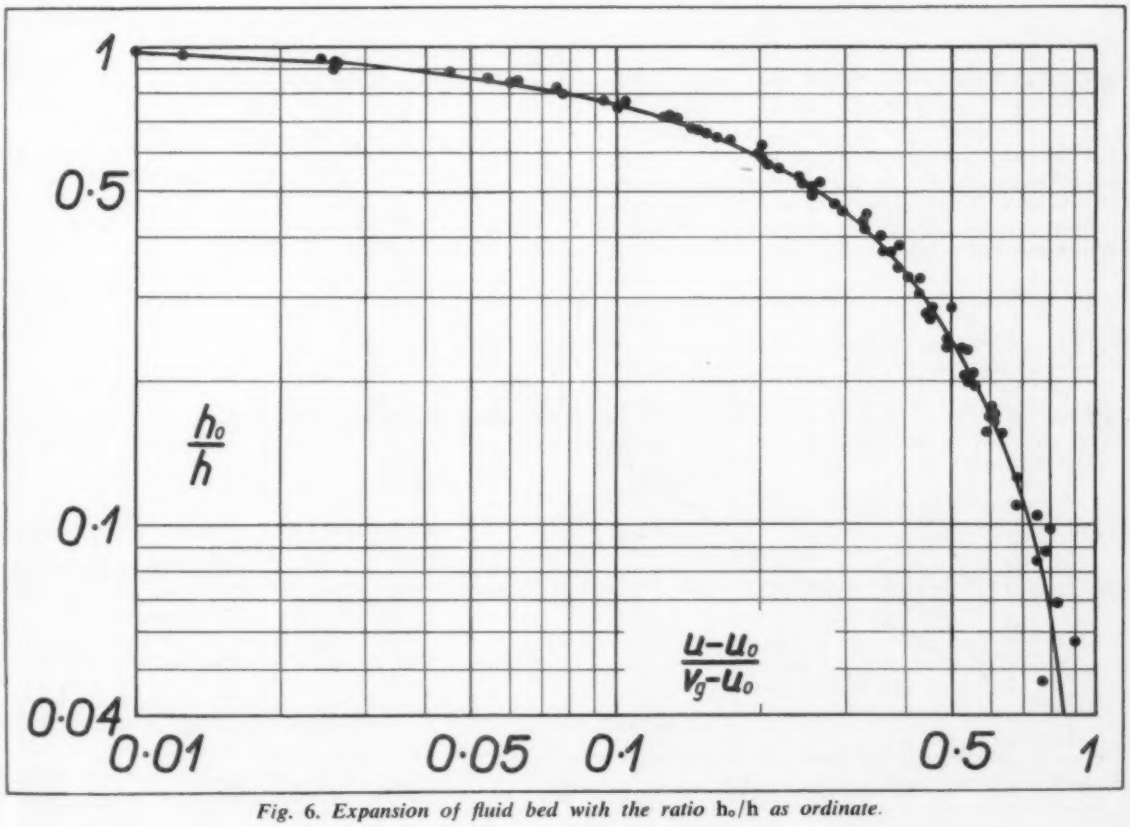

Fig. 6. Expansion of fluid bed with the ratio h_0/h *as ordinate.*

Applications of the Theory

The foregoing theory will be used to design a reactor for converting naphthalene to phthalic anhydride by catalytic oxidisation. The temperature of reaction (400°C) and a vanadium catalyst supported on silica gel will be employed. Data:

density of air	
at 20°C	1.164 kg/m³
at 400°C	0.508 kg/m³
kinematic viscosity of air	
at 20°C	1.57×10^{-5} m²/sec
at 400°C	6.49×10^{-5} m²/sec
specific density of catalyst	
silica-gel carrier ...	2200 kg/m³
porosity of particles ϵ_s	0.60 kg/m³
bulk weight of the silica gel ...	670 kg
average weight of a silica gel grain	
size 0.43-0.75 mm. ...	4.4×10^{-7} kg
ϵ_0	0.492
molecular weight of phthalic anhydride	148
molecular weight of naphthalene	128

Example I

It is required to find the dimensions of a fluidised-bed reactor capable of producing 300 metric tons of phthalic anhydride per year. The following information is given: the concentration is 0.05 kg of naphthalene in Nm³ of air; the pressure on the catalyst is 0.05 kg of naphthalene per hour per kg of the catalyst; the conversion is 80% of the theoretical value; one year equals 7000 hours; the size of the silical-gel particles, carrying the catalyst is 0.43-0.75 mm.

Naphthalene concentration = 0.05 Kg/Nm³ air

Catalyst loading = 0.05 Kg/hr. kg catalyst
Conversion = 80%
Particle size range of silica-gel carrier = 0.43-0.73 mm
Hours operating per year = 7000

SOLUTION

The first thing is to estimate the flow of naphthalene and air to be fed to the reactor.

300 tonnes phthalic anhydride p.a. = 0.0119 kg/sec.

Naphthalene required $= 0.0119 \cdot \frac{128}{148} \cdot \frac{1}{0.8}$

$= 0.0129$ kg/sec.

The air flow = 0.0129/0.05 = 0.258 Nm³/sec.

At 400°C this volume = 0.636 m³

The volume of naphthalene vapour $= 0.0129/128 \cdot \frac{673}{273} \cdot 22.4$

$= 5.6 \times 10^{-3}$ m³/sec.

The total flow of reactants = 0.636 + 0.006 = 0.642 m³/sec.

The average critical velocity has next to be found. Part A of the instrument (see Fig. 2) is filled with 30 gm of silica gel particles, of the given range m sizes, and the following typical results are obtained.

△m (gm)	u (m/sec)	△m/m
30.00	0	1
30.00	1.28	1
29.13	1.76	0.971
25.95	1.98	0.865
22.26	2.18	0.742
17.04	2.21	0.568
13.26	2.59	0.442
7.53	2.94	0.251
3.60	3.05	0.120
0.66	3.34	0.022
0	3.45	0

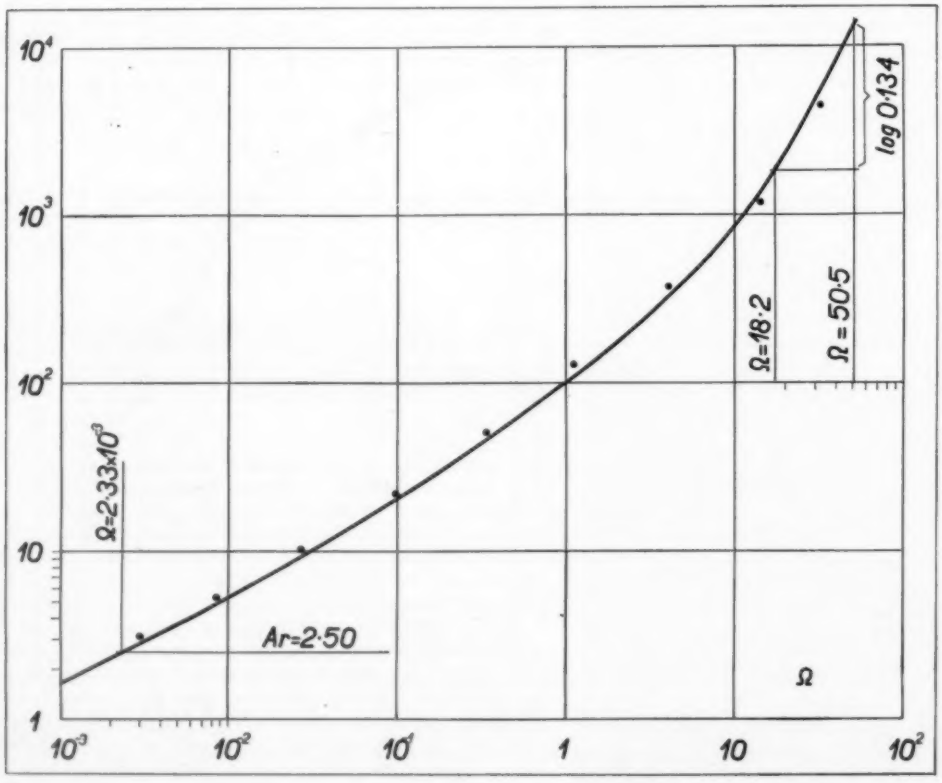

Fig. 7. Archimedes' number **Ar** *plotted against the criterion for the silica-gel particles. (Similar to Fig. 1, but extended to suit practical needs.)*

The values of Δ m/m are plotted against u in Fig. 3, from which the following values of critical velocities are obtained.

v_g min. = 1.60 m/sec.
v_g = 2.45 m/sec.
v_g max. = 3.48 m/sec.

The criterion Ω at 20°C is then

$$\Omega = \frac{v_g^3 \rho_f}{g \nu \rho_z}$$

$$\Omega_{20} = 2.45^3 \times 1.164/9.81 \times 1.57 \times 10^{-5}\ 2200 = 50.5$$

The curve obtained for silica gel is plotted in Fig. 7. At 20°C the flow is turbulent.

The criterion Ω at 400°C can be obtained by two different methods. If the flow passing the particles falls in either the laminar or turbulent regions the numerical method is preferred. If, however, the flow is in the transient region a graphical method can be used to better advantage.

Graphical Method

First of all, the ratio of Archimedes' numbers for 20° and 400°C is found. This ratio depends only on the physical parameters of the fluid. Thus:

$$\frac{Ar_{400}}{Ar_{20}} = \frac{(\rho_f \nu^2)_{20}}{(\rho_f \nu^2)_{400}} = \frac{1.164 \times 1.57^2}{0.508 \times 6.49^2} = 0.134$$

Next a vertical line is put through the point $\Omega_{20} = 50.5$ (Fig. 7) and the intersection of this line and the silica-gel curve is found. Then a horizontal line is drawn at the distance equal to log 0.134, from the intersection point, measured along the vertical line. If the horizontal line is sufficiently extended it again intersects the silica-gel curve. This point gives the value of the criterion at 400°C, namely $\Omega_{400} = 18.2$.

Numerical Method

The criterion in the turbulent region can be expressed as $\Omega = k_2 \sqrt{Ar}$ so that the ratio of Archimedes' numbers becomes $\Omega_{400}/\Omega_{20} = (Ar_{400}/Ar_{20})$ and $\Omega_{400} = 50.5 \sqrt{0.134} = 18.5$.

In the laminar region $\Omega = k_1 Ar^2$ and the same method of calculation can be applied. In the transient region the coefficient is continuously variable between 2 and $\frac{1}{2}$ and therefore the graphical method is more convenient.

It remains to find the value of the terminal velocity at 400°C:

$$v_{g(400)} = \left(\frac{\Omega_{400}\, g\, \nu\, \rho_z}{\rho_f}\right)^{\frac{1}{3}}$$

$$= \left(18.5 \cdot 9.81 \cdot 6.49 \cdot 10^{-5} \cdot 2200 \cdot \frac{1}{0.508}\right)^{\frac{1}{3}}$$

$$= 3.70 \text{ m/sec.}$$

The velocity at the threshold of fluidisation at 400°C is given by Equation (5):

$$\frac{u_o}{v_g} = 0.045 \cdot 0.492 \cdot 18.5^{0.2} = 0.0396$$

and $u_o = 0.0396 \times 3.70 = 0.146$ m/sec.

On the assumption that

$$\left(\frac{v_{g\ \text{min.}}}{v_g}\right)_{400} = \left(\frac{v_{g\ \text{min.}}}{v_g}\right)_{20}$$

and the velocity at which the particles begin to be blown away:

$$u_v = 1.60 \times \frac{3.70}{2.45} = 2.42 \text{ m/sec.}$$

The dimensions of the reactor can now be determined. The foregoing calculations show that the gas velocity must lie in the range 0.146-2.42 m/sec. Therefore, 0.4 m/sec. will be selected. This speed is low enough to allow for changes which may be necessary at the beginning of the production.

Thus the cross-sectional area of the vessel $= \frac{0.642}{0.4} = 1.6$ m² and its diameter = 1.4 m.

According to the given loading, the weight of the layer of catalyst is:

$$0.0129 \times \frac{3600}{0.05} = 930 \text{ kg.}$$

so that the corresponding volume is

$$\frac{930}{670} = 1.39 \text{ m}^3$$

The height (h_o) of the unexpanded bed becomes

$$\frac{1.39}{1.6} = 0.87 \text{ m.}$$

The expansion of the bed will be obtained from (9)

$$\frac{u - u_o}{v_g - u_o} = \frac{0.254}{3.546} = 0.0715$$

From Fig. 6

$$\frac{h_o}{h} = 0.85 \text{ and } h = \frac{0.87}{0.85} = 1 \text{ m.}$$

Example 2

It is required to cool the gases before they enter the filters. The cooler extends over the length of the reactor, measured from its bottom to the filters, to 4 m. A suitable fluid velocity has to be determined.

Now $\frac{h_o}{h} = \frac{0.87}{4} = 0.217$

and from Fig. 6

$$\frac{u - u_o}{v_g - u_o} = 0.55$$

hence $u = 0.55 \times 3.546 - 0.146 = 1.804$ m/sec.

Example 3

It is required to find the maximum size of particle which can be blown away by gases travelling at 0.4 m/sec. Assuming that the particles are in the "blow-away" region, the fluid velocity equals the terminal velocity of the particles, i.e., $u = v_g$. The values of the criteria are then from Fig. 7.

$\Omega_1 = 0.4^3 \cdot 0.0508/9.81 \cdot 6.49 \cdot 10^{-5} \cdot 2200 = 2.33 \cdot 10^{-3}$ and $Ar_1 = 2.5$.

The apparent weight of the silica-gel particles, size 0.43 — 0.75 mm, is $Z_s = 4.4 \times 10^{-7}$ kg and the corresponding Archimedes' number is Ar = 2010. The ratio $\frac{Ar}{Ar_1}$ is independent of the physical parameters of the fluid, provided the temperature is constant and identical fluids are considered.

Thus $\frac{Ar}{Ar_1} = \frac{Z_s}{Z_{s1}} = \frac{kd^3_s}{kd^3_{s1}}$

and the required average size of the particle is:

$$d_{s1} = \frac{(0.430 + 0.750)}{2} \frac{\sqrt[3]{2.5}}{\sqrt[3]{2010}} = 0.055 \text{ mm}$$

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CALCULATION OF THE TRANSIENT BEHAVIOUR OF DISTILLATION COLUMNS — PART I

Methods for solving distillation calculations for binary systems are examined and the most promising is found to be the digital electronic computer. Two programmes are described

by H. H. ROSENBROCK, B.Sc. (Eng)., Ph.D., A.M.I.E.E.

THE transient behaviour of plate-type distillation columns for binary systems has been studied theoretically by a number of authors,[1,2] and there is general agreement about the equations which apply. Some experimental work to check these equations has also been reported[3,4,5] and good agreement between calculated and measured responses has been found. The equations, however, in their general form are not easy to solve, and for this reason a number of simplifying assumptions are usually made. The experimental system is then chosen so that the assumptions are as nearly as possible satisfied. While this avoids mathematical difficulties, it limits the choice of the experimental system and narrows the field over which the theory can be checked.

The work described here was undertaken in order to find a more general method of solving the equations. Four applications for such a method were foreseen:

(i) to extend the range over which experimental confirmation of the equations could be made;

(ii) to follow the course of batch distillations;

(iii) to find the equilibrium time and steady-state performance of continuously-operating industrial columns as an aid to their design; and

(iv) to study the effect of disturbances on industrial columns as an aid to the design of suitable control systems.

Of these, (ii)-(iv) required not only to have a very general method of solution but also to have one which was economical. A method, described in Section 5, using an electronic digital computer was finally developed. The preliminary investigation of the equations, of the assumptions involved, and of the possible methods of solution is described in Sections 1, 2 and 3. Section 4 gives details of the first computer programme which was developed. This gave correct results, but was uneconomic for large numbers of plates.

It is hoped that the existing programme for binary mixtures will serve as a first step towards a more general programme for multi-component systems.

1. Statement of the Equations

Fig. 1 shows the conditions in a plate-type distillation column. Taking a material balance for the more volatile

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Symbols

a, b = constants in the equation describing the curve $y^* = f(x)$ (Section 2); also dividing points between the intervals of tabulation of x as defined in Section 4;
c = time intervals δt as defined in Section 10;
E = Murphree vapour efficiency;
f = time at which a value of F is changed;
$f(x,p)$ = equilibrium relation $y^* = f(x,p)$;
$f(x)$ = equilibrium curve for a mean value $\bar{p}$ of p, $f(x) = f(x,\bar{p})$;
F = feed rate in mols per sec. (product take-offs are sometimes regarded as negative feeds);
h = mols of vapour hold-up (Sections 1 and 2); also time at which a value of H is changed (Section 10);
H = mols of liquid hold-up;
k = number of different values of δt used in a calculation;
l = time at which a value of L is changed;
L = liquid flow rate in mols per sec.;
m = number of time-steps calculated with a fixed value of δt;
n = number of plates in the column;
p = pressure; also a number of time-steps (Section 10);
$\bar{p}$ = mean pressure in the column;
P = product take-off rate, mols per sec.;
q = a constant;
t = time;
T = temperature;
v = time at which a value of V is changed;
V = vapour flow rate in mols per sec.;
x = mol fraction of the more volatile component in the liquid leaving a plate or the condenser;
x' = defined so that Hx' is the amount in mols of the more volatile component in the hold-up H;
X = delayed value of x as defined in Section 10;
y = mol fraction of the more volatile component in the vapour leaving a plate or the reboiler;
y' = defined so that hy' is the amount in mols of the more volatile component in the hold-up h;
y^* = mol fraction of the more volatile component which is in equilibrium with liquid of composition x;
Y = delayed value of y as defined in Section 10;
z = mol fraction of the more volatile component in the feed or in the product;
Z = time at which a value of z is changed;
α = relative volatility;
δ = intervals of tabulation of x as defined in Section 4; also as a prefix denotes a small increment;
ϵ, η = small constants; and
θ = constant between 0 and 1 in Equation (20);
τ = time delay for liquid flow between condenser and column.

SUBSCRIPTS

r = distinguishes the plates ($r = 1$ to $r = n$) or the reboiler ($r = 0$) or condenser ($r = n + 1$); and
s = those values of r corresponding to plates to which a feed is supplied, or to the reboiler or condenser from which products are taken off.

Distillation column at Stanlow Refinery. The design of such equipment for binary separations and of systems for their control can be facilitated by computer-aided methods. (Photo: Shell Co.)

component around the condenser, we obtain:

$$\frac{d}{dt}(H_{n+1}x'_{n+1}+h_{n+1}y'_{n+1}) = V_n y_n - L_{n+1}x_{n+1} - P_{n+1}x_{n+1} \quad \ldots.(1)$$

From a material balance for both components we have

$$\frac{d}{dt}(H_{n+1} + h_{n+1}) = V_n - L_{n+1} - P_{n+1} \quad \ldots.(2)$$

Similarly for the rth plate,

$$\frac{d}{dt}(H_r x'_r + h_r y'_r) = V_{r-1}y_{r-1} - V_r y_r + L_{r+1}x_{r+1} - L_r x_r + F_r z_r \quad \ldots.(3)$$

$$\frac{d}{dt}(H_r + h_r) = V_{r-1} - V_r + L_{r+1} - L_r + F_r \quad \ldots.(4)$$

where F_r will be zero except when $r = s$. For the reboiler we have:

$$\frac{d}{dt}(H_0 x'_0 + h_0 y'_0) = -V_0 y_0 + L_1 x_1 - P_0 x_0 \quad \ldots.(5)$$

$$\frac{d}{dt}(H_0 + h_0) = -V_0 + L_1 - P_0 \quad \ldots.(6)$$

These Equations, (1) to (6), can be summarised in the following pair of equations

$$\frac{d}{dt}(H_r x'_r + h_r y'_r) = V_{r-1}y_{r-1} - V_r y_r + L_{r+1}x_{r+1} - L_r x_r + F_r z_r \quad \ldots.(7)$$

$$\frac{d}{dt}(H_r + h_r) = V_{r-1} - V_r + L_{r+1} - L_r + F_r \quad \ldots.(8)$$

where we must understand

$$\left.\begin{aligned} V_{-1} = L_0 = V_{n+1} = L_{n+2} = 0, \\ F_0 = -P_0,\ F_{n+1} = -P_{n+1},\ z_0 = x_0,\ z_{n+1} = x_{n+1} \end{aligned}\right\} \quad \ldots.(9)$$

The relation between y and x can be written in terms of the MURPHREE vapour efficiency and the equilibrium curve

$$y_0 = y^*_0 \quad \ldots.(10)$$

$$\frac{y_r - y_{r-1}}{y^*_r - y_{r-1}} = E_r,\ r = 1, 2, \ldots, n \quad \ldots.(11)$$

$$y^* = f(x, p) \quad \ldots.(12)$$

Equations (7) to (12) are the equations governing mass-transfer.

2. Discussion of Assumptions

The assumptions which have been made in developing Equations (7) to (12) are not important. Equations (7) and (8) express simple material balances and are exact, since x' and y' are suitably-defined mean values. Equation (1) assumes that the vapour from the reboiler is in equilibrium with the liquid from which it arises. If this is not true, the equation may be replaced by a more accurate relation. Equations (11) and (12) at this stage merely define E_r and involve no assumption.

Equations (7) to (12) do not in themselves determine a solution, and further equations are required. These further equations must be based upon appropriate assumptions, which usually include some or all of the following:

(i) $x'_r = x_r$. This will not generally be true, since the liquid on a plate becomes less rich in the more volatile component as it flows from inlet to outlet.

(ii) E_r is independent of time. Thus the vapour efficiency of the plates under transient conditions is assumed to be the same as under steady conditions.

(iii) $h_r = 0$.

(iv) H_r is independent of time. When this assumption

is made, batch distillations cannot be considered. An effect of assumptions (iii) and (iv) is to neglect the delay which must in practice occur before a change of liquid flow rate to one plate causes a corresponding change of liquid flow rate on lower plates. This delay is not the same as the time required for liquid to travel from the upper plate to the lower ones, and may be much less. The same assumptions also neglect the smaller but similar delay between a change of vapour flow rate in one part of the column and the corresponding changes of vapour flow rate in other parts of the column.

(v) V_r, L_r and F_r are independent of time. The assumption implies, with assumptions (iii) and (iv), that the liquid throughout the column is always at its boiling point.

(vi) $V_{r-1} = V_r$, except at the feed plate or plates (where $r = s$). It follows from Equation (8) and assumptions (iii) and (iv) that $L_{r+1} = L_r$ except when $r = s$.

(vii) y^* is unaffected by the differences of pressure which exist within the column. Thus p in $y^* = f(x, p)$ is replaced by a mean pressure $\bar{p}$

(viii) (a) $y^* = ax + b$, ...(13)

or (b) $y^* = \alpha x/[1 + (\alpha - 1)x]$, ...(14)

or (c)
$$\left.\begin{aligned} \frac{y^*}{1-y^*} &= \frac{ax}{1-x} + b,\ x_c < x \leqslant 1 \\ \frac{1-y^*}{y^*} &= \frac{a'(1-x)}{x} + b',\ 0 \leqslant x < x_c \end{aligned}\right\} \quad \ldots.(15)$$

where

$$\left.\begin{aligned} &\pm\sqrt{(aa')} \pm \sqrt{(bb')} = 1 \\ &\frac{x_c}{1-x_c} = \sqrt{\left(\frac{a'b}{ab'}\right)} \end{aligned}\right\} \quad \ldots.(16)$$

Assumptions (viii), (a), (b) and (c) are alternative assumptions about the form of $f(x)$. The first replaces the equilibrium curve over a limited range by a straight line. The second applies only to ideal systems which obey RAOULT's and DALTON's laws. The third is due to CLARK[6] and includes the second as a special case.

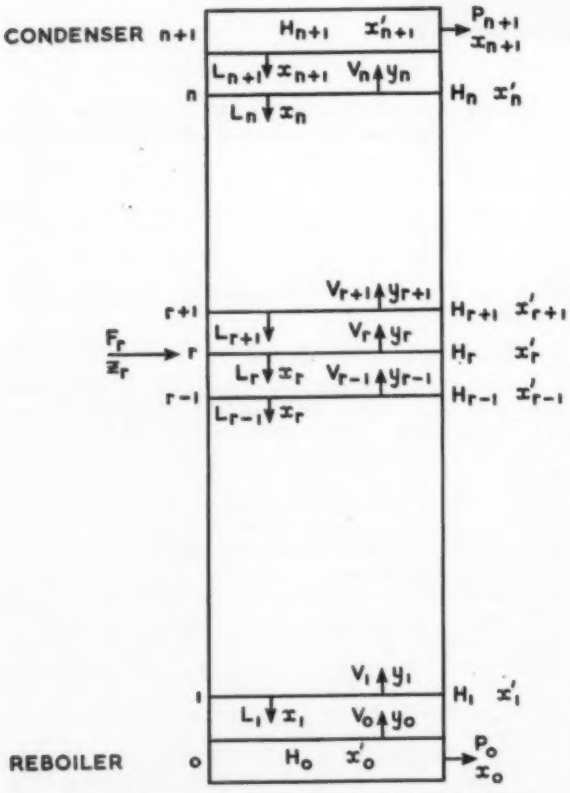
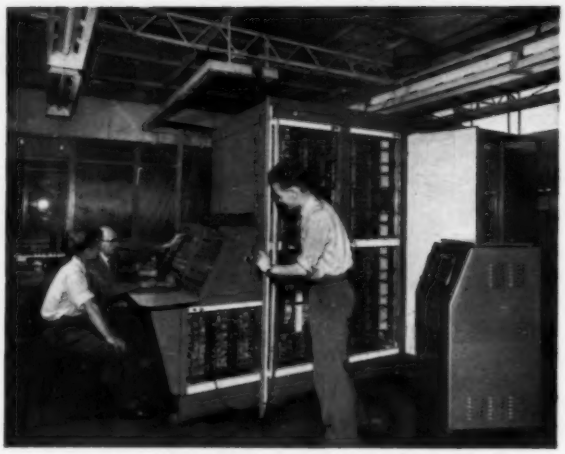


Fig. 1. Diagram of separation of a binary mixture illustrating conditions existing in a plate-type distillation column.



Apprentices receiving instruction in the use of the Deuce digital computer. (Photo: English Electric.)

(ix) E_r has the same value E for every plate.

(x) $E = 1$, so that the plates become "theoretical plates" and no longer correspond with those in the actual column.

(xi) H_r has the same value H for every plate; that is, $H_r = H$, $r = 1, 2, \ldots, n$.

The combination of assumptions which is required depends on the method of solution.

3. Discussion of Methods of Solution

Five possible methods of solution were considered, and the following conclusions were reached:

3.1. LAPLACE TRANSFORMATION

In the application of this method it is usual to make assumptions (i) to (vii), (viii) (a), (ix), (x) and (xi). Of these, assumptions (iii), (vi), (ix), (x) and (xi) can be avoided but only at the expense of a considerable increase in the amount of work. The most restrictive of the remaining assumptions is probably (viii) (a), which is unavoidable.

The method is very suitable for qualitative studies, but it is not sufficiently general, and it is too laborious.

3.2. PERTURBATION METHODS

If the equilibrium condition of a column can be found, the classical theory of perturbations[5,7] can be applied to find the effect of small disturbances. The result is a set of linear differential equations to which the Laplace transformation may be applied. An analytical solution for the equilibrium condition can be found with assumptions (i) to (vii), (ix), (x) and (viii) (b),[1] or, more generally, (viii) (c).[6] Some of these assumptions might be avoided, but the method is not suitable since it is laborious and does not allow the initial approach to equilibrium to be followed.

A variant of the method, used by VOETTER,[5] is to approximate to the equilibrium curve by two straight lines, one for plates above the feed and one for those below. If the slope of each line bears the same ratio to the slope of the appropriate operating line, the resulting equations take a specially simple form. This device reduces the amount of work, but only at the expense of a loss in generality.

3.3. GRAPHICAL METHOD

Some of the difficulties of an analytical solution are evidently due to the non-linear, and in general arbitrary, form of the relation between y^* and x. This type of diffi-

culty can often be avoided by graphical methods, and an attempt was therefore made to solve the equations graphically. It was found, however, that the method developed was too laborious and too inaccurate to be useful.

3.4 Use of an Analogue Computer

An electronic analogue computer offers a very flexible and powerful means for solving differential equations, and Equations (7) to (12) can certainly be solved by the use of such a computer.[8]

The use of an analogue computer was nevertheless rejected for the following reasons:

(i) One of the problems which had to be solved concerned the behaviour of columns for isotope separation. The accuracy demanded in the function $y^* = f(x)$ for this problem was beyond anything that could reasonably be expected of an analogue computer. Moreover, the number of plates (several hundreds) would demand an extremely large machine.

(ii) For an arbitrary function $y^* = f(x)$, one function-generator is required to simulate each plate. No analogue computer with more than a very small number of function-generators was known to be available.

(iii) It was felt that if machine methods were to be used, a digital computer would be better suited to this problem.

The use of an analogue computer is probably most profitable for studying the detailed behaviour of a column with a given control system when its operation is disturbed. For this purpose, the equations can be linearised in the vicinity of the working point, and the use of function-generators can thus be avoided.

3.5 Use of a Digital Computer

None of the methods considered above seemed to offer any hope of a quick and accurate solution to the general equations. It is quite easy, however, to write down a procedure for solving Equations (7) to (12) by direct numerical integration. One such procedure is to start with known liquid compositions x throughout the column at time $t = 0$, and to compute the changes in these values of x after successive intervals of time in the following way:

(i) Find $y^*_0, y^*_1, \ldots, y^*_n$ from $y^* = f(x)$.

(ii) Find $y_0, y_1, \ldots, y_n$ from
$y_0 = y^*_0$
$y_1 = E_1\ y^*_1 + (1 - E_1)\ y_0, \ldots,$ etc.

(iii) Find $\delta x_0, \delta x_1, \ldots, \delta x_{n+1}$ from

$$H_r \frac{dx_r}{dt} = V_{r-1}y_{r-1} - V_r y_r + L_{r+1}x_{r+1} - L_r x_r + F_r z_r \quad \ldots . (17)$$

(iv) Find new values of x from $x_0 + \delta x_0$, $x_1 + \delta x_1$, etc., and repeat stages (i) to (iii). Proceed until no δx exceeds a chosen small amount.

Such a routine has already been used for hand[9] and machine[3] calculations, and it is well suited to an electronic digital computer. The equilibrium data $y^* = f(x)$ can be fed in either as an equation or as a table of values between which the machine can interpolate. The power and flexibility of the machines are such that the necessary assumptions are no longer dictated by the process of obtaining a solution. Any assumptions can be used, and provided that they define a solution it can be obtained by an appropriate numerical routine. The limitations are likely to be the practical ones that the physical conditions may not be known in sufficient detail to allow the writing of suitable equations, and that the time for computation may become too great.

It was therefore decided to write a programme for a digital computer in order to solve Equations (7) to (12). The progress of the first programme to be written will be described in Section 4 to be published in Part 2 of this article. *(To be continued)*

First Bradwell Heat Exchanger

THE completion recently of the first of 12 heat-exchanger shells for the Bradwell nuclear power station in the shops of Head Wrightson & Co. Ltd., Thornaby-on-Tees, Yorks., marked a milestone in the work of the company. Not only had the shell been finished to standards which Sir John Wrightson, vice-chairman of the company, thought had not been attained previously, but it was also one of the largest fabrications to have been built on the site. Ocean towage from the Tees to the power station on the Blackwater, Essex, has been chosen as the method of transport for the shell and the others that are to follow during the next 11 months.

Each exchanger, which is to receive 3,000,000 lb. an hour of contaminated carbon dioxide at 734°F, and is to deliver steam at 770 psia at 704°F in quantities of 170,833 lb. an hour, is a vertical pressure-vessel of 1⅜-in. plate, 19 ft in diameter, 92 ft high and 200 tons in weight. Internally, each will be cleaned to "almost clinical standards" and the surfaces will be covered with colloidal graphite to prevent damage by condensation during transport. Two and a half times as much steam will be produced by each new unit as is produced by its counterpart at Calder Hall, for a "very little" increase in size, and the improved performance reflects, Head Wrightson point out, the work of the Nuclear Power Plant Co.'s combined research team on which they are represented.

All plate material used in the vessels was supplied by Consett Iron to BSS 1501-154, the shell plate being from grade C and the dished ends from the more ductile grade B. The metal was chosen for its suitability at service temperatures in excess of 700°F, its weldability, notch ductility and freedom from cracking. Tests and precautions carried out during fabrication of the shells included ultrasonic checks of the plates as received from the rolling mills, for flaws and laminations, radiography and stress-relieving of the ring sections of the vessel; halogen-gas leak-tests of the welding of each of the 1200 thermal sleeves; and X-ray testing of the welding of the dished ends.

For stress-relieving of the completed structure a special power station was installed to ensure uniformity of the heating current (see p. 404). The shell was lagged with Stillite insulating mattresses and was raised (over 25 hours) to a temperature of 630°C, using internally-suspended, radiant-electric heaters provided by Whessoe Ltd. It cooled down over four days and the efficiency of the insulation was shown by the fact that during the first four hours the temperature dropped by only 12°C. After cooling, the vessel was stripped and subjected to an air test and to a hydrostatic test at a pressure of 270 psi. The tubes will be installed on site. Although the heat exchanger was the first piece of plant to be launched by the company for sea transport, it is planned to use the same method in the future for chemical equipment, such as large cat crackers.

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CORROSION OF METALS CONNECTED TO GRAPHITE COMPONENTS

Metallic plant components connected to graphite equipment may, in service, undergo severe corrosion. An investigation of this problem and how it can be controlled is discussed in this article

by T. K. ROSS, M.Sc., Ph.D., M.I.Chem.E., AM.Inst.F.

THE increasing use of carbon and graphite equipment in the chemical industry is witness of the satisfactory resistance of this material to a wide range of corrosive conditions. However, some reports from industry have indicated that the introduction of single graphite units in a plant has resulted in increased attack in other sections of the system. Thus the role of the graphite in such a circumstance is of some importance to the engineer concerned with materials selection. For example, in one case connected piping and adjacent vessels made of normally-resistant materials have been corroded when a graphite heat exchanger was introduced into the system.

Experimental Method

Experiments have been conducted with industrial graphite in conjunction with mild steel, copper, lead, stainless steel, nickel and titanium, and exposed to dilute sodium chloride solutions of various *p*H values. Potential-current-type polarisation investigations predicted corrosion patterns which were in the main confirmed by static weight-loss measurments. Two series of experiments were carried out: in the first prepared metal specimens were connected to specimens of carbon or graphite, and the coupled pairs partly immersed in dilute (N/1000) sodium chloride solutions, of which the *p*H value had previously been adjusted to 3.0, 7.0 and 11.0. The polarisation characteristics of both members of the couple were measured whilst the oxygen content of the solution was maintained by means of a slow bubble-feed from a cylinder. In all cases the temperature of the solution was 25°C during the investigation. The potential curves were plotted from data taken during the first 15 minutes after immersion of the specimens, and confirmed at the end of the first hour.

In the second set of experiments metallic and carbon speciments were short-circuited after partial immersion in test solutions similar to those previously described, and the loss in weight of the metal recorded at timed intervals. The maximum duration of these tests was 40 days.

In both series of experiments, the metallic and carbon specimens were waxed and immersed so as to expose an area of 10 sq. cm. on each specimen.

Materials Used

Test solutions were prepared from analytical-grade sodium chloride and distilled water, and *p*H adjustments to values of 3.0, 7.0 and 11.0 were made with N/100 NaOH or N/100 HCl.

Three types of carbon were used, all of which were of a type commercially available in Great Britain. This material is made by a process of carbonisation of bituminous coal, followed by thermal graphitisation and final impregnation of the pores with a resinous material. Speci-

Dr. Ross, *who is an authority on corrosion and corrosion control, is a senior member of the Chemical Engineering Staff of the Manchester College of Science and Technology.*

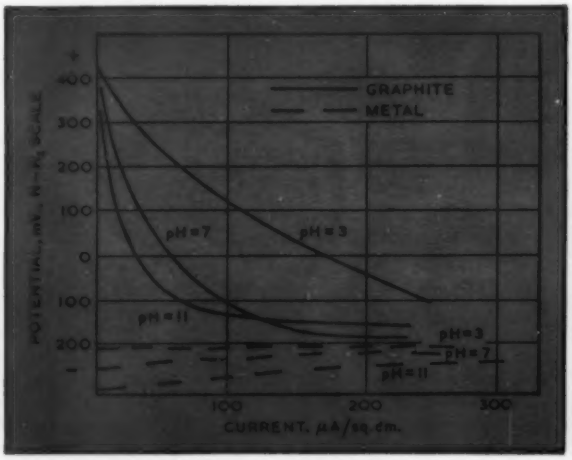

Fig. 1. Polarisation curves for mild steel.

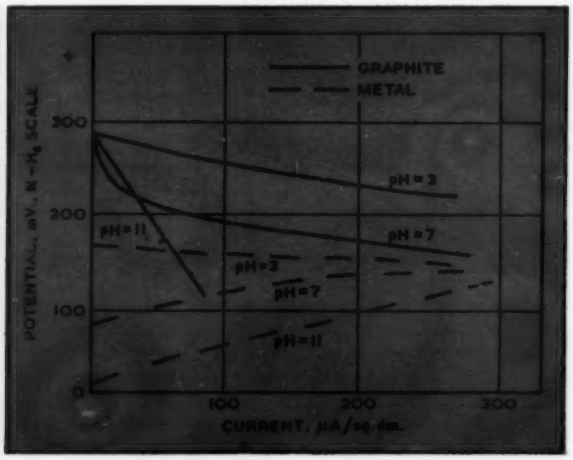

Fig. 2. Polarisation curves for copper.

mens were prepared from grades representing all three stages of this process; namely, carbon, graphite and impregnated graphite. In fact, only the latter is of great interest industrially as a constructional material, due to the porosity of the other two types, and results obtained with this grade are reported here. In general, the use of unimpregnated material resulted in exaggerated (i.e., more corrosive) conditions. The material was roughly sized and then waxed to provide accurate immersion areas, but was not surface-treated in any way.

The metals used in opposition to these carbon specimens are specified below.

Mild Steel:	C 0.07%, Mn 0.38%, Cr 0.03% Si 0.003%, S 0.24%, P 0.026%
Copper:	Fe 0.002%, Bi 0.0015%, Se 0.013% Ni 0.004%, As 0.002%, Ag 0.004%, O_2 0.02%
Lead:	Cu 0.003%, Sb 0.002%, Bi 0.004% Fe 0.002%, Ag 0.002%, Ni 0.001%
Stainless Steel:	Cr 18%, Ni 8%, Ti 0.6%, C 0.32%, Si 1.2%
Nickel:	Cu 0.1%, Fe 0.15%, Si 0.06% Mn 0.2%, C 0.1%
Titanium:	Cr 0.01%, O_2 0.002%, N_2 0.001%, Fe 0.005%

Specimens were cut from sheet to an approximate size of 2 cm × 10 cm and the edges and the lower part of the front degreased in alcohol and lightly abraded with fine emery paper. After a final wash in ethanol, the back and edges were waxed, and sufficient of the front so as to leave an exposed area of 10 sq. cm at the lower end. Specimens were stored in a desiccator until required.

Results Obtained

Mild Steel

(a) Fig. 1 shows the polarisation curves obtained with clean mild-steel specimens coupled to impregnated graphite when immersed in solutions of three *p*H values. It is at once obvious that the graphite places the steel at a disadvantage by providing a cathodic surface which is not only cathodic towards the steel, but shows some degree of polarisation. In alkaline and neutral solutions the corrosion current is limited to about 300 μA./sq. dm. In more acid conditions the polarisation is not so pronounced, which allows a considerable corrosion current to flow.

(b) Long-term observations of the corrosion rate of mild steel connected to carbon and graphite in neutral sodium chloride solutions were carried out. It was found that the corrosion of the steel was at the rate of 180 mgms. per sq. dm. per day when connected to impregnated graphite, and that this was four times the control value.

Copper

(a) The polarisation curves obtained with copper specimens are shown in Fig. 2. Again, the tendency of the carbon surfaces to behave as cathode towards the metal is noticeable, together with the polarisation characteristics of the impregnated material. It is also noteworthy that this effect is most obvious in neutral conditions, and the least so in acid solutions.

(b) In the static long-term experiment in neutral conditions, the corrosion rate averaged only 12 mgms. per sq. dm. per day when connected to impregnated graphite. These weight losses represent a serious reversal in the behaviour of copper in such mildly corrosive conditions, for as the control experiment shows, the normal result is a slight gain in weight due to oxidation.

Lead

(a) Fig. 3 shows the results of the polarisation studies of lead specimens coupled to the available grade of carbon. It may be seen that this metal could be expected to corrode very rapidly in these circumstances in the absence of any secondary protective film formation of the surface. It would also appear that the influence of *p*H upon the attack would not be very marked, and that corrosion would proceed at much the same rate in acid and alkaline conditions.

(b) The long-range tests confirmed these impressions, and initial loss at the rate of 120 mgms. per sq. dm. per day was experienced with impregnated graphite. A typical slimy white deposit formed during these tests, and this did appear to have a slightly protective effect. Even so, after 40 days' exposure, a current flow of 125 μA/sq. dm. between lead and impregnated graphite could be recorded, indicating that dissolution would continue at a serious rate.

Stainless Steel

(a) The results portrayed in Fig. 4 suggest that the danger of reduced corrosion resistance is not great when carbon or graphite is connected to alloys of this type. However, in slightly acid conditions, where stainless steel would normally be resistant, the curves indicate that even when coupled to impregnated graphite a worsening of resistance could occur.

(b) The weight loss experiments tended to confirm these views, for loss of weight was generally very small indeed—only 1 mgm. per sq. dm. per day when coupled to impregnated graphite—but the figures are none the less suggestive when compared with the behaviour of uncoupled stainless steel, and especially in view of the fact that the attack is continuous. Small quantities of rust were visible in these experiments—again an unusual fact when dealing with this class of alloy, and suggesting that the metal is dangerously near the border-line between resistance and failure.

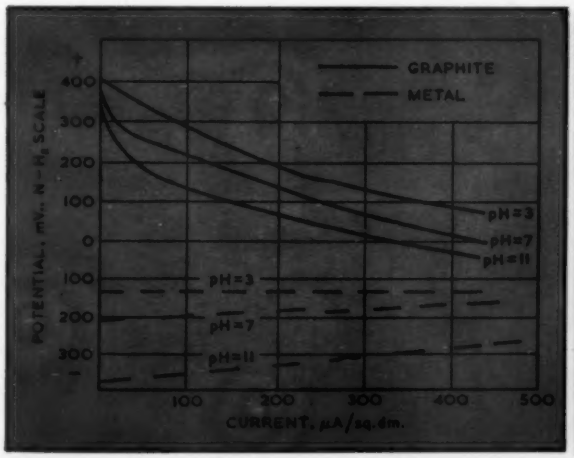

Fig. 3. Polarisation curves for lead.

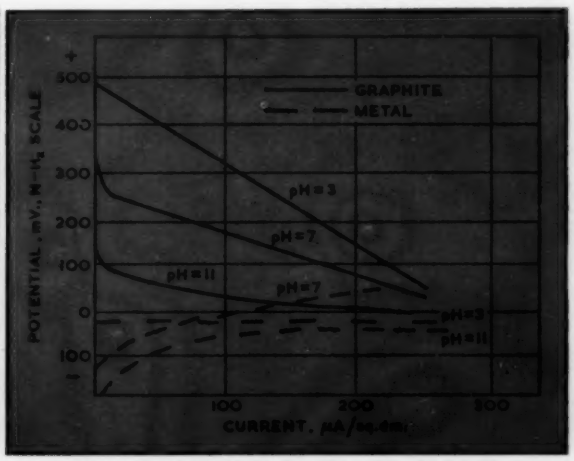

Fig. 4. Polarisation curves for stainless steel.

NICKEL

(a) The data of Fig. 5 show how the corrosion resistance of nickel in both alkaline and neutral solutions persists when coupled to graphite. Susceptibility to acid attack is, as in the case of stainless steels, probable, if not extensive.

(b) Long-range tests of up to 40 days revealed no significant weight loss in neutral solution, thus confirming the predictions of the polarisation plots.

TITANIUM

(a) Titanium has almost ideal properties when in electrical contact with carbon, being as polarised anodically as the carbon is cathodically. Thus, although there is a substantial difference in polarity between the two surfaces when an open circuit, the resistance of the metallic ionising processes limits the flow of corrosion current to virtually negligible proportions, as shown in Fig. 6.

(b) Weight-loss tests confirm these findings, and even on protraction to 100 days no significant weight loss could be recorded.

Discussion

It has been shown that the grade of carbon used possesses an open circuit surface potential which is positive towards that of mild steel, copper, lead, stainless steel, nickel and titanium when immersed in oxygenated dilute-sodium-chloride solutions of various *p*H. However, polarisation and weight-loss studies show that the degree of increased corrosion which a given metal experiences when coupled to graphite is often less than would be expected.

Mild steel, for example, is heavily attacked even in alkaline conditions when connected to carbon or graphite. This is due to the readiness with which cathodic processes proceed on the carbon surfaces. There is practically no obstacle to the continuance of cathodic depolarisation by means of dissolved oxygen when connected to graphite. The impregnated material, however, does show marked polarisation and weight-loss studies show that the degree of corrosion of the steel. This reduction is most marked in alkaline and neutral solutions where the cathodic process is essentially one involving hydrogen ions, electrons and dissolved oxygen. In more acid conditions, where hydrogen ions and electrons are principally involved, the steepness of the curve is initially reduced, and so a more damaging condition persists.

That this should occur with a metal whose electrode potential is in any case unfavourable is not surprising, but that similar results are obtained with a semi-noble metal such as copper is of more importance. The initial cathodic role of the graphite surface is maintained by its depolarisation, and inspection of Fig. 2 suggests how this is mostly concerned with the oxidative mechanism occurring in neutral and alkaline solutions. Thus, although the impregnated material is heavily polarised in neutral solutions, it is less so in alkaline conditions; in acid surroundings it behaves much as do the unimpregnated samples. The attack is, however, progressive, and so it is apparent that when the dual protective mechanisms of semi-nobility and hydrogen ion overpotential, which copper normally enjoys, are undermined in this way, its resistance is lost.

In much the same way, the corrosion resistance of lead is practically destroyed when connected to graphite. In addition, it is obvious that the formation of insoluble corrosion products in a partially retentive form causes, as time passes, a slackening of the initial heavy corrosion.

A more encouraging situation exists when metals which possess means of resistance other than those of nobility or overpotential are tested. An alloy—for example, stainless steel—relies for its successful corrosion resistance upon its ability to form an oxidised film which resists further transport of metallic ions to the surface. Thus, although such an alloy is electronegative towards carbon, when both are immersed in an electrolyte the metal is not able to provide ions at the surface of its wetted air-formed film. In this case corrosion does not proceed rapidly, but it is possible that repair of fractures in the film is impaired and some attack is probable. In acid conditions particularly, when the metal surface cannot increase its passivity, a dangerous situation is predicted by Fig. 4.

Nickel and titanium are both materials which function successfully because of film protection coupled with a reluctance to ionise. Although nickel is at its best in alkalis and titanium in acids, the polarisation data suggest that resistance when coupled to carbon would not be greatly impaired, and weight-loss tests confirm this.

The conclusions to be drawn from the investigation are:

First, none of the customary service metals can be considered entirely free from the risk of accelerated corrosion when used in conjunction with graphite or carbon equipment. They are all initially electronegative towards carbon, and may be forced into an anodic role unless steps are taken to electrically insulate the two materials.

Secondly, resistance to attack in these circumstances must be based upon phenomena other than those of electropositive or noble behaviour, or hydrogen overpotential. Resistance must be sought in those materials with obstructive film-forming properties or a marked reluctance to ionise at anodic sites.

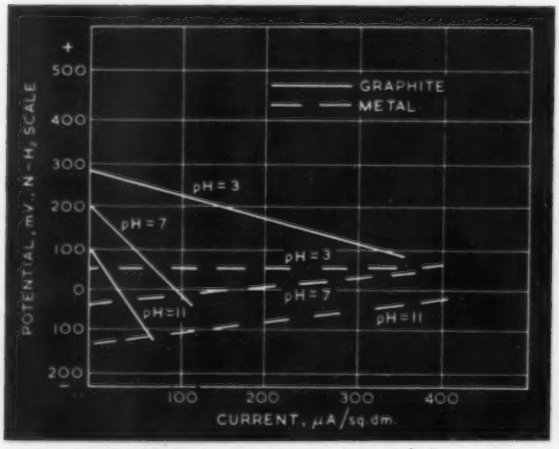

Fig. 5. Polarisation curves for nickel.

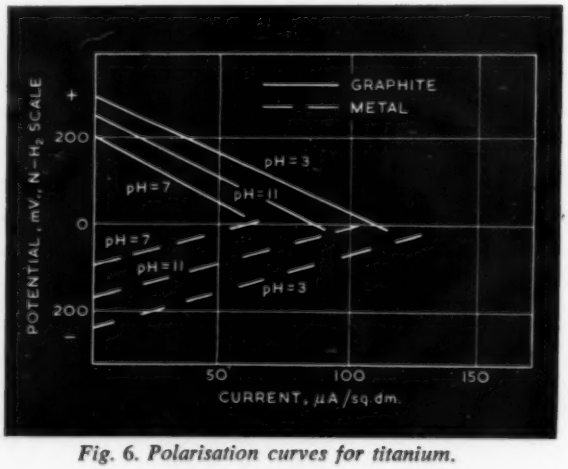

Fig. 6. Polarisation curves for titanium.

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CHROMATOGRAPHY IN AROMATICS REFINING

GAS-LIQUID chromatography can be of considerable help to a plant manager as a routine and an investigational tool in the production of by-products of the carbonising industry to stringent specifications. In benzole refining the present tendency is to treat at large central refineries the crude benzole production from a number of carbonisation units. The crude stocks are usually blended in the ratio in which they are received and are passed to a primary rectification stage which frequently operates continuously. Here the crude benzole is split into four major fractions: (*a*) light forerunnings, (*b*) 90s benzole, (*c*) 90s toluole and (*d*) once-run xylole. After acid washing these products are further fractionated, usually batchwise, to give the corresponding pure products.

Throughout, strict quality control is necessary. The side-arm distillation test has become established as the principal method of control and, although there can be no questioning its value with commercially pure products, its usefulness with the complex crude or partially-refined products is dubious. The time factor involved with efficient fractional distillation rules that method out: gas-liquid chromatography, however, produces the same result in a much shorter time and probably with greater accuracy. A complete quantitative analysis on a crude benzole can be carried out by this method in a matter of half an hour, and, by testing all the incoming crudes in this way, the blending can be intelligently conducted so as to produce a feed to the continuous primary rectification section of virtually constant and known composition. The actual composition of the crude feed can be used to determine the quantities of 90s products which should be made. The plant running conditions can be adjusted to give such yields, and, if changes have to be made in the crude feed, alterations can be made to the plant. Strict control of quantities in this way virtually guarantees uniformity of the products. After acid washing, the 90s materials are ready for the final rectification and it is at this stage that a comprehensive knowledge of the constitution of the batch is of great value, as it permits the estimation of the likely production of the corresponding pure material. With conventional testing techniques a number of specification tests must be carried out throughout the whole distillation. But with foreknowledge of the estimated production, conventional testing can be restricted to the beginning and end of the distillation. In all distillation processes of this type it is impossible to avoid the formation of intermediate products. Frequently these are returned to the system indiscriminately, as it is not possible by existing techniques to assess their value.

The illustration (Fig. 1) shows a chromatogram of a typical washed 90s benzole. By measuring the areas under the peaks, it can be shown that this sample contains 79% of pure benzene, and, assuming a 90% recovery of this benzene as a commercially pure product, the net yield from the final rectification will be 71% of the batch. This percentage will vary from one plant to another, depending on the nature of the crude, but, with a constant feedstock, it should remain reasonably constant for any particular plant.

The applications of gas-liquid chromatography in the tar distillation industry are different, as it is not usual to refine products to the same extent as in the benzole industry, and the technique does not appear to have been used widely

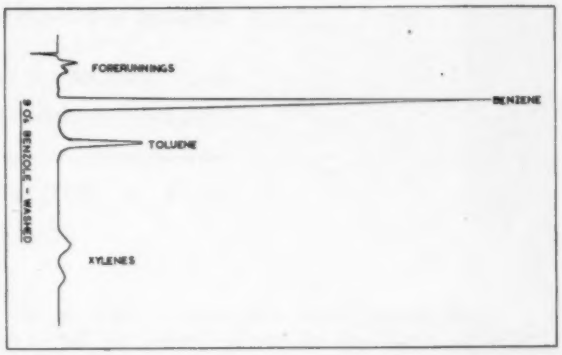

Fig. 1. Chromatogram of a typical washed 90s benzole.

for routine testing. There are, however, a number of possible uses. In the production of indene/coumarone resins, for example, the starting material is a heavy naphtha in which the indene and coumarone have been concentrated by a distillation procedure. Existing methods for testing such material involve a rather empirical determination of the unsaturateds content. With chromatographic techniques, using a column at about 180°C, it should be easy to determine the actual indene and coumarone contents and, by correlating distillation ranges with chromatographic analyses, it should be possible to lay down a distillation procedure that will yield the desired product without having to carry out many long tedious tests.

Use in Solvent Extraction

When producing phthalic-grade naphthalene by hot pressing or solvent extraction techniques it is often of great value to a manager to know the nature of the impurities in the product. There is no way of gaining this information except by long, complicated analyses unsuitable for plant control. Chromatographic techniques would not resolve all the minor traces of impurity, but they would at least give a general idea of the nature of the compounds involved. In solvent extraction processes gas-liquid chromatography would provide a rapid method of determining residual solvent in the product, and it would be sufficiently speedy to allow a manager the opportunity to act on the information.

The present standard method for determining anthracene in crude pastes takes a matter of three days and requires an experienced analyst. A chromatographic column operating at a temperature of about 300°C should be able to do the same job in about one hour. There is very little reported experience of the technique at such temperatures, but there is no apparent reason why it should not be operated successfully. With existing stationary phases the life of a column would not be great but this difficulty should not prove insurmountable.

Chromatography should also provide a satisfactory method of determining the constitution of the crude tar acids and bases which are produced at some plants. In these and in other ways the use of gas-liquid chromatography in the carbonisation industry in the near future may well be considerably extended.

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DESIGNING A GAS-COOLING TOWER

Economic factors in the design of gas-cooling towers are reviewed and two methods of calculating the transfer surface are compared

by S. J. MICHELL, M.Sc., A.M.I.Chem.E.

AMONG factors which contribute towards the economic dimensions of packed towers, the gas-liquid ratio is of primary importance. This, in turn, depends on the outlet temperatures. Although often selected arbitrarily, the outlet temperatures should—as far as conditions permit—be based on economic grounds. In the following discussion, the factors which are to be taken into account in design practice are briefly reviewed. Two methods of calculating the packing height are also presented, and the application of the discussed principles is shown in the following numerical example.

Economic Factors

Unless the conditions make the use of wood impossible, wooden grids are the recommended material in gas cooling. There is then no need for the selection to be made on an economic basis. The remaining variables, which will be fixed on economic grounds, are the outlet temperatures and the cross-sectional area.

The Outlet Temperatures

The outlet gas temperature may sometimes have to be fixed to meet a specification, otherwise it will be selected on economic grounds. According to Jackson,[1] an ideal approach to the water inlet temperature of 4°F is justified on an economic basis, but in design practice a 5° to 7°F approach is preferable. This does not lead to any marked deviation from the optimal figure.

According to the same reference, the optimal value of the exit water temperature can be obtained on the assumption that the enthalpy of the saturated gas, corresponding to the exit water temperature, is the mean of the enthalpies of saturated gas corresponding to the inlet gas temperature and the inlet water temperature, both being fixed by the data. It will be observed, however, that this rule does not find application in wider cooling ranges, in which case it is the water-gas ratio which determines the water outlet temperature.

The Area of Cross-section

The cross-sectional area is determined primarily by the economic superficial gas velocity. Regardless of its economic value, the gas velocity should not exceed what is known as the Loading Point. At the same time, operation under fully wetted conditions should be ensured. For packed towers, the Minimum Wetting Rate (M.W.R.) can be established from the following relation:

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Symbols Used

A = transfer area, sq. ft;
a = specific surface of packing, sq. ft/cu. ft;
C_p = specific heat of dry gas, Btu/(lb.) (°F);
C_s = humid heat, Btu/(lb.) (°F);
d = equivalent diameter of gas passage, in.;
f = mean enthalpy factor;
G = gas rate, on dry basis, lb./hr;
g = acceleration due to gravity, 32.2 ft/sec.²;
H = absolute humidity, lb./lb.;
h = convectional heat-transfer coefficient, Btu/(hr) (sq. ft) (°F);
i = enthalpy, Btu/lb.;
K_g = overall mass-transfer coefficient, lb./(hr) (sq. ft) (atm.);
L = water rate, lb./hr;
M = molecular weight;
n = number of velocity heads lost per ft of packing height;
p = partial pressure of water, atm. or mm;
p_f = partial pressure of non-diffusing component, atm.;
ρ = dry gas density, lb./cu. ft;
ρ_L = density of water, lb./cu. ft;
S = area of cross-section, sq. ft;
V = volume of packed section, cu. ft;
v = superficial velocity of dry gas, ft/sec.;
v_g = relative velocity of gas and liquid surfaces, ft/sec.;
λ = latent heat of condensation, 1076 Btu/lb. at 32°F.
Z = height of packed section, ft.
g, w = subscripts referring to dry gas, and water (or interface), respectively.

$$\text{M.W.R.} = \frac{L}{S \cdot a \cdot \rho_L} \qquad \ldots (1)$$

where L = liquid rate (lb./hr);
S = cross-sectional area (sq. ft);
a = specific surface of packing (sq. ft/cu. ft); and
ρ_L = density of liquid (lb./cu. ft).

Using the above dimensions, the term M.W.R. will be expressed in (cu. ft/(hr) (ft)) units. It has been verified[2] that for all packings, with the exception of rings of diameter greater than 3 in. and grids of pitch greater than 2 in., the complete wetting is ensured when the M.W.R. term exceeds a value of 0.85. For the larger sizes, the corresponding figure is 1.3 cu. ft/(hr) (ft).

In the absence of reliable experimental data on Loading Points, the generalised correlation (after Lobo, *et al.*),

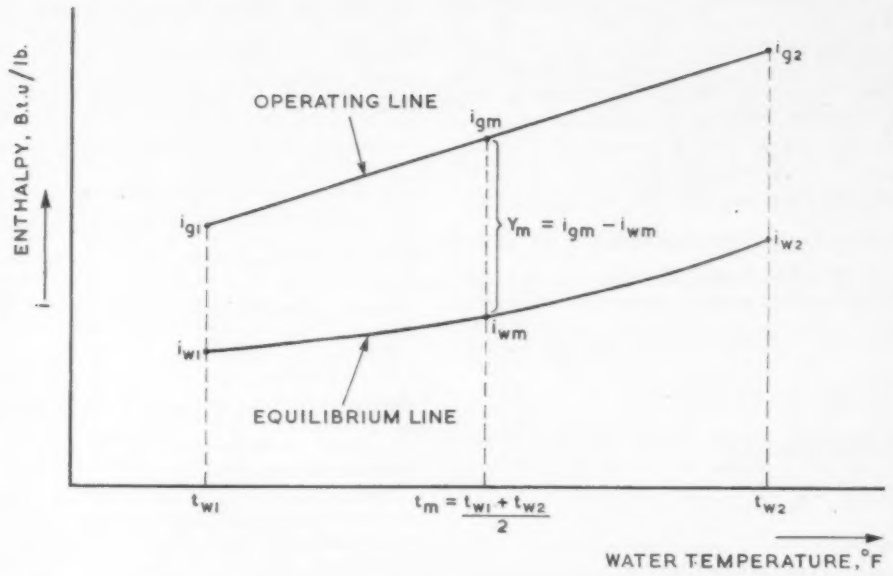

Fig. 1. Enthalpy-temperature diagram used for obtaining enthalpy-based driving forces.

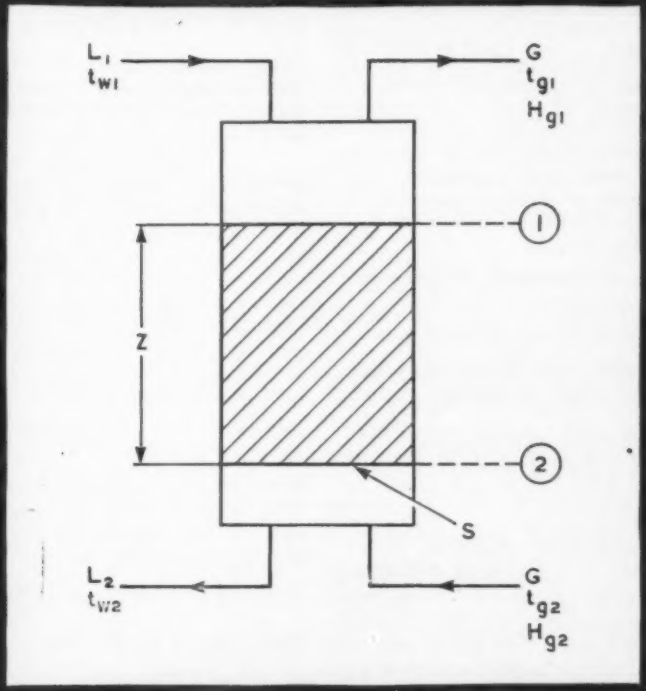

Fig. 2. Diagram of direct contact cooling process giving an explanation of symbols used.

given by SHERWOOD,[3] may be used for the determination of Flooding Point. A safety margin of about 50% should then be allowed for.

ECONOMICAL GAS RATE

Following usual assumptions, the economic gas-rate equation will be derived by analytical method.

Theoretical power required for a fan to convey a gas of mean density, ρ (lb./cu. ft), at the rate of G (lb./hr), through a tower offering $\triangle p$ (lb./sq. ft) pressure drop is given by the following relation:

$$\text{hp} = \frac{\triangle p}{\rho} \cdot \frac{G}{550 \times 3600} \qquad \ldots.(2)$$

Replacement of the pressure head term by velocity head, $\frac{\triangle p}{\rho} = n \,.\, Z \,.\, v^2/2g$, in which ($n$) is the number of the velocity heads lost per ft of packing height, (Z) being the total height, in ft, and substitution of the linear velocity, v, (ft/sec.) by mass rate, $G = v \,.\, s \,.\, \rho \times 3600$, so that $\frac{\triangle p}{\rho} = \frac{n \,.\, Z}{2g} \cdot \left(\frac{G}{S\rho}\right)^2 \cdot \left(\frac{1}{3600}\right)^2$, leads to

$$\text{hp} = \frac{1}{(550)\,(3600)^2\,(64.4)} \,.\, n \,.\, Z \,.\, G \left(\frac{G}{S\rho}\right)^2$$

$$\therefore \text{hp} = 6.06 \times 10^{-16} \times n \,.\, Z \,.\, G \left(\frac{G}{S\rho}\right)^2$$

Let: C_1 = the cost of power (pence/kWh);
θ = hours of operation per year; and
e = overall efficiency.

Adding 10% for maintenance, the annual operating charges per cu. ft of packed space (C_2), in shillings, are given by:

$$C_2 = \frac{1.1 \text{ hp}}{1.34\,S\,Z} \cdot \frac{\theta}{e} \cdot \frac{C_1}{12}$$

$$= \frac{(1.1)\,(6.06) \,.\, 10^{-16}}{(1.34)\,(12)} \cdot \left(\frac{\theta}{e}\right)\left(\frac{n}{S}\right)\left(C_1\,G\right)\left(\frac{G}{S\rho}\right)^2$$

$$\therefore C_2 = 4.15 \times 10^{-17} \,.\, \frac{\theta}{e} \,.\, n\, C_1\, \rho \left(\frac{G}{S\rho}\right)^3 \qquad \ldots.(3)$$

For a given duty, the tower volume (V, cu. ft) is inversely proportional to the mass transfer coefficient (K_g), which, in turn, may be taken as being proportional to two-third power of the linear velocity, so that

$$V \propto 1/K_g \propto v^{-\frac{2}{3}}$$

In terms of mass rates we may therefore write:

$$V = k \left(\frac{G}{S\rho}\right)^{-\frac{2}{3}}$$

in which (k) is a proportionality constant. Let also: C_3 = capital charges, per cu. ft of tower, in shillings; and r = years of depreciation.

The total annual charges (C_T) are then given by:

$$C_T = V\ (C_2 + C_3)$$

By substitution,

$$C_T = k \left(\frac{G}{S\rho}\right)^{-\frac{2}{3}} \left[4.15 \,.\, 10^{-17} \,.\, \frac{\theta}{e} \,.\, n \,.\, C_1\, \rho \left(\frac{G}{S\rho}\right)^3 + \frac{C_3}{r}\right]$$

$$\therefore C_T = k \left[4.15 \,.\, 10^{-17} \,.\, \frac{\theta}{e} \,.\, C_1\, n\, \rho \left(\frac{G}{S\rho}\right)^{2.25} + \frac{C_3}{r} \left(\frac{G}{S\rho}\right)^{-0.75}\right]$$

Differentiation with respect to G, setting the derivative equal to zero, and rearrangement, gives;

$$G^3 = \frac{0.75}{(2.25)\,(4.15)} \cdot 10^{-17} \cdot \left(\frac{C_3}{r\,C_1}\right)\left(\frac{e}{\theta}\right) \cdot \left(\frac{1}{n\,\rho}\right)\left(\rho\,S\right)^3$$

$$G = 2.01 \times 10^5 \,.\, (\rho\,S) \left[\left(\frac{C_3}{r\,C_1}\right)\left(\frac{e}{\theta}\right)\left(\frac{1}{n\,\rho}\right)\right]^{\frac{1}{3}}$$

On unit cross-section basis, the economic mass velocity, $G_E = \frac{G}{S}$, is therefore given by:

$$G_E = 2.01 \,.\, 10^5 \,.\, \rho \,.\, \left[\left(\frac{C_3}{r\,C_1}\right)\left(\frac{e}{\theta}\right)\left(\frac{1}{n\,\rho}\right)\right]^{\frac{1}{3}} \qquad \ldots.(4)$$

Assuming a five-year depreciation period, the term $\left(\frac{C_3}{r\,C_1}\right)$ may reasonably be taken equal to 8; assuming also 50% overall efficiency and 8400 working hours per year, Equation (4) reduces to:

$$G_E = 2.01 \times 10^5 \,.\, \left[(8)\left(\frac{0.5}{8400}\right)\right]^{\frac{1}{3}} \cdot (\rho) \,.\, \left[\frac{1}{n\,\rho}\right]^{\frac{1}{3}}$$

$$\therefore G_E = 15{,}700 \left[\frac{\rho^2}{n}\right]^{\frac{1}{3}} \qquad \ldots.(5)$$

In its final form, Equation (5) is expressed in lb./(hr) (sq. ft).

Transfer Area

Having fixed the cross-section of the tower, the volume of the packed section, and hence its height, can be established upon the evaluation of the transfer area required for the duty. This may be done either on a heat- or mass-transfer basis, depending on which cofficient is at hand. In water-insoluble gas systems, of which the gas cooling operation is a typical example, the gas film coefficient is a controlling factor and may, therefore, replace the overall coefficient in rate equation without sensible error. The two different approaches, both on mass-transfer basis, which have been adopted in the numerical part of this article, have the following theoretical background.

GRAPHICAL METHOD

On an hourly basis, a combination of material balance and rate equation may be written in the following differential form:

$$dL = K_g \,.\, dA \,.\, \triangle p = G \,.\, dH_g \qquad \ldots.(6)$$

in which (dL) represents a small amount of water, in lb., picked up by (G) lb. of dry gas, resulting in the increase of its humidity by an amount equal to (dH_g), expressed in lb. per lb. of dry gas. The transfer takes place by diffusion across the interfacial area of (dA) sq. ft, when the instantaneous driving force is equal to ($\triangle p$) atm. The consistency of units requires that the (K_g) coefficient is expressed in lb./(hr) (sq. ft) (atm.) units.

Assuming operation under normal atmospheric pressure, the following relation holds:

$$H = \frac{p}{1-p} \cdot \frac{M_w}{M_g}$$

where M_w/M_g is the water-gas molecular weight ratio. Since the partial pressure is negligibly small in comparison with the total pressure of one atmosphere, the equation may be simplified to the form:

$$H = \frac{M_w}{M_g} \,.\, p$$

from which it follows that:

$$\triangle p = \frac{M_g}{M_w} \,.\, \triangle H \qquad \ldots.(7)$$

Substitution to Equation (6) gives:

$$K_g \,.\, dA \,.\, \triangle H \,.\, \frac{M_g}{M_w} = G \,.\, dH_g \qquad \ldots.(8)$$

Rearrangement and integration between the two limits, namely the top (1) and the bottom (2) of the packed section, leads to equation

$$A = \int_1^2 dA = \frac{G}{K_g} \cdot \frac{M_w}{M_g} \cdot \int_1^2 \frac{dH_g}{\triangle H} \qquad \ldots . (9)$$

Solution of Equation (9) requires evaluation of the integrated term. The log-mean difference approach has not been found applicable to problems dealing with simultaneous transfer of mass and heat occurring; consequently, graphical integration is the alternative. Working up the column by increments, the number of diffusion units required for the process can be established, providing us with the data for the integration. The technique adopted by BRAS[4] in his problem on heat-transfer basis avoids trial-and-error procedure, and can be employed here as an intermediate step leading to the graphical integration.

The steps involved in the procedure will be briefly introduced with reference to Fig. 3. The straight lines on the temperature-humidity plot in Fig. 3, such as (*a-a'*), (*b-b'*), (*c-c'*), etc., represent instantaneous driving forces, in magnitude and direction, at the corresponding sections of the tower. Any intermediate point on any such line, say point (*b*) on line (*a-a'*), may be selected arbitrarily to mark the starting point of the next line (*b-b'*), the length and the slope of which are found from mass- and heat-balances. The new line thus indicates the change in condition on reaching the next section above. The steps are repeated by small increments until the conditions of the top section are reached.

ENTHALPY METHOD

The total cooling effect in a tower is due to the heat transferred by convection (q_c) and that due to diffusion (q_d). For a differential element of the tower, the corresponding rate equations are:

$$d\ q_c = h \,.\, dA \,.\, (t_g - t_w) \qquad \ldots . (10)$$

$$d\ q_d = \lambda \,.\, K_g \,.\, dA \,.\, (p_g - p_w) \qquad \ldots . (11)$$

where (h) is the convectional heat-transfer coefficient, (λ) the latent heat of condensation, while (t_g) and (t_w) are the temperatures in the main stream of the gas and in the interface, respectively; the other terms have the meanings as explained already.

Replacement of partial pressures by humidities (Equation 7), and addition of the two equations, leads to the "total heat" equation:

$$dq = h \,.\, dA \,.\, (t_g - t_w) + \lambda \,.\, K_g \,.\, dA\,(H_g - H_w) \,.\, \frac{M_g}{M_w} \ldots . (12)$$

The mass- and heat-transfer coefficients are related to each other by "LEWIS equation" of the form

$$\frac{h}{K_g' \, C_s} = \text{Le}$$

in which (Le) is the "LEWIS number" and (C_s) the humid heat (Btu/lb.):

Since $K_g' = K_g \,.\, \frac{M_g}{M_w}$, then

$$h = K_g \,.\, \frac{M_g}{M_w} \,.\, C_s \,.\, \text{Le}$$

Substitution to Equation (12) and rearrangement gives:

$$dq = K_g \,.\, \frac{M_g}{M_w} \,.\, dA\ [C_s\,(\text{Le})\,(t_g - t_w) + \lambda\,(H_g - H_w)] \qquad \ldots . (13)$$

MERKEL and his followers have indicated the way of simplifying the "total heat" equation with reference to water cooling. Based on the assumption that the LEWIS number equals unity, which is nearly true for the air-water system, Equation (13) can be reduced to a very convenient form. A marked deviation from this assumption may, however, be observed for other than air-water systems. For the diffusion of water into gases, such as hydrogen and carbon dioxide, for example, the LEWIS numbers are about 2.0 and 0.6 respectively.[5] Nevertheless, supported by experimental data, CARVEY and WILLIAMSON[6] have shown that the MERKEL's approximation can be extended to gas-cooling problems without serious loss in accuracy. Moreover, inspection of Equation (13) leads to at least one favourable conclusion—namely, that unless the molecular weight of the gas exceeds that of air, one is on the safe side taking unity for LEWIS number. We can therefore, write Le = 1, and so reduce Equation (13) to the form:

$$dq = K_g \,.\, \frac{M_g}{M_w} \,.\, dA \,.\, [C_s\,(t_g - t_w) + \lambda\,(H_g - H_w)] \qquad \ldots . (14)$$

It may be observed that the square-bracketed term represents the difference between the enthalpy in the main gas stream (i_g) and that in the interface (i_w). Equation (14) then simplifies to:

$$dq = K_g \,.\, \frac{M_g}{M_w} \,.\, dA \,.\, (i_g - i_w) \qquad \ldots . (15)$$

Making use of a chart,[7] the ($i_g - i_w$) term of Equation (15) may conveniently be replaced by its mean value, $(\triangle i)_m$, so that

$$dq = K_g \,.\, \frac{M_g}{M_w} \,.\, dA \,.\, (\triangle i)_m \qquad \ldots . (16)$$

Originally developed by STEVENS and reproduced in reference 7, the chart enables evaluation of a factor, f, which when multiplied by the mean enthalpy difference, Y_m, as obtained from the enthalpy diagram represented in Fig. 1, gives the mean value with sufficient accuracy. The factor makes an allowance for the departure from straight-line relationship of the operating line.

The factor 'f' can be obtained from the chart[7] upon the evaluation of $\frac{Y_m}{Y_1}$ and $\frac{Y_m}{Y_2}$ ratios. With reference to Fig. 1, the symbols are related to enthalpies by the following equations:

$$Y_m = i_{gm} - i_{wm} \qquad \ldots . (17)$$

$$Y_1 = i_{g1} - i_{w1}$$

$$Y_2 = i_{g2} - i_{w2}$$

The mean enthalpy is then calculated from

$$(\triangle i)_m = f \,.\, (Y_m) \qquad \ldots . (18)$$

Integration of Equation (16) gives:

$$q = \frac{M_g}{M_w} \,.\, K_g \,.\, (\triangle i)_m \,.\, \int_1^2 dA \qquad \ldots . (19)$$

But the total heat transferred is also given by:

$$q = G\,(i_{g2} - i_{g1}) \qquad \ldots . (20)$$

Equating to (19), the solution for A gives the transfer-area equation in its final form:

$$A = \int_1^2 dA = \frac{M_w}{M_g} \cdot \frac{G}{K_g} \cdot \frac{(i_{g2} - i_{g1})}{(\triangle i)_m} \qquad \ldots . (21)$$

Numerical Example

Problem: A process gas mixture is to be cooled at the rate of 50,000 lb./hr, on dry basis, to a temperature which must not exceed 80°F. The average molecular weight of the gas is 20 and its dew-point is 100°F. Required is the specification of the plant equipment.

Solution: It is proposed to cool the gas by direct contacting with water which is assumed to be available at a temperature not exceeding 68°F. Normal working pressure and adiabatic operating conditions are also assumed.

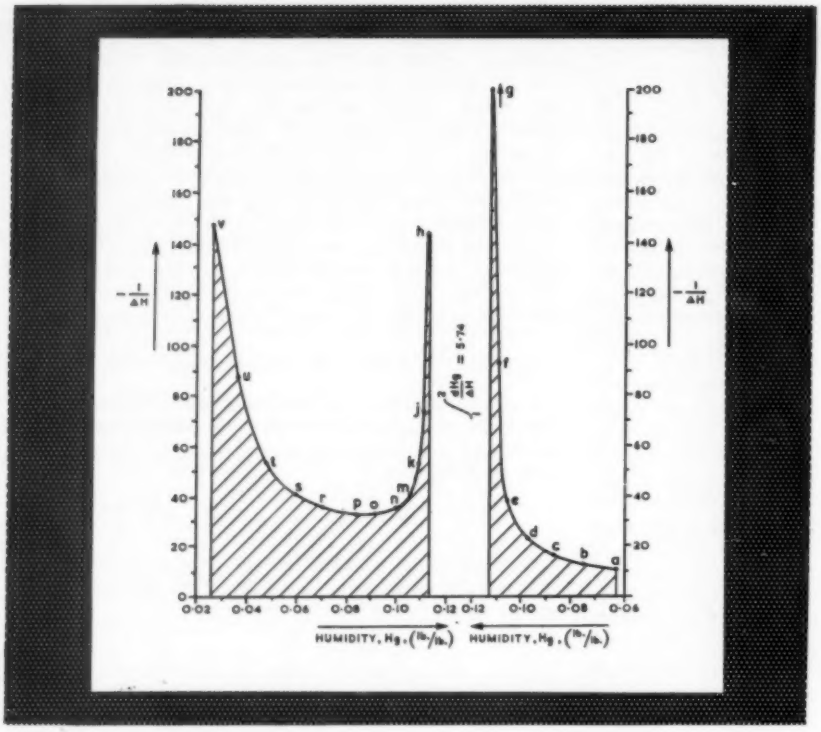

Fig. 3. Temperature - humidity diagram, showing procedure for obtaining data for graphical integration of the term $\int_1^2 \frac{dH}{H}$

THE OUTLET TEMPERATURES

Referring to Fig. 2, the known quantities are:

The inlet water temperature, $t_{w1} = 68°F$.

The inlet gas temperature, $t_{g2} = 440°F$.

The rate of dry gas, $G = 50{,}000$ lb./hr.

With a 7°F approach, which is within the economic range, the outlet temperature of the gas will be fixed at $t_{g1} = 75°F$.

It has been already stated that for wider cooling ranges the mean enthalpy rule cannot be employed in fixing the outlet water temperature. It is then the water-gas ratio which will establish its value. The water-outlet temperature should be kept low enough to produce a reasonable driving force at the bottom end of the tower; on the other hand, it should not exceed a certain value otherwise the cross-sectional area will be too large or flooding within the economic gas range may occur. A rough estimation indicates that the conditions will be met by an outlet temperature of $t_{w2} = 130°F$.

WATER-GAS RATIO

For the gas entering the tower with the dew-point of 100°F (corresponding to a partial pressure of 49 mm), the absolute humidity is: $H_{g2} = \frac{49}{760-49} \cdot \frac{18}{20}$

$$\therefore H_{g2} = 0.062 \text{ lb./lb. dry gas.}$$

Similiarly, the humidity of the gas leaving the tower, assumed saturated at the exit temperature of 75°F (partial pressure = 22.2 mm), is $H_{g1} = 0.0271$ lb./lb.

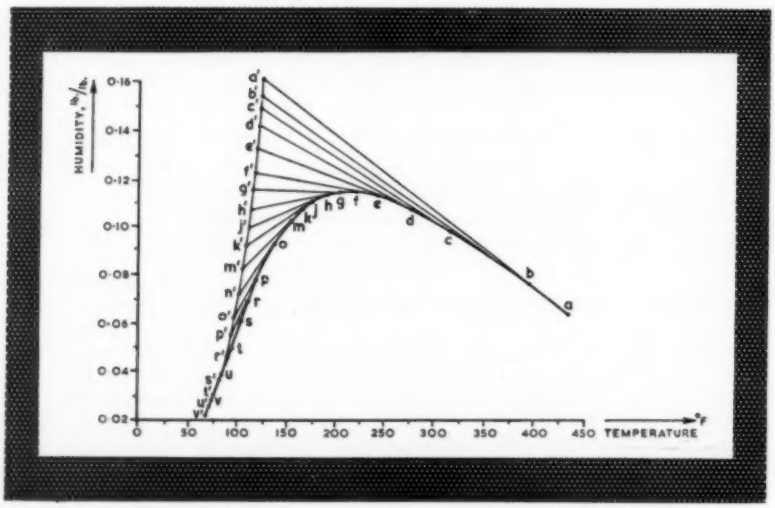

Fig. 4. Graphical integration of $\int_1^2 \frac{dH}{H}$ *for evaluating the cooling tower transfer area.*

$$\therefore \triangle H_g = 0.0620 - 0.0271 = 0.0349 \text{ lb./lb.}$$

On the assumption that specific heats of dry gases are approximately inversely proportional to the molecular weigths, the specific heat of the cooled gas may be taken equal to:

$$C_p = 0.24 \cdot \frac{29}{20} = 0.35 \text{ Btu/lb.}$$

Taking also 0.5 for the specific heat of steam, the respective enthalpies of the wet gas at the outlet and inlet conditions are:

$$i_{g1} = 1076\ (0.0271) + (75 - 32)\ [0.35 + 0.5\ (0.0271)]$$
$$\therefore i_{g1} = 44.37 \text{ Btu/lb.}$$
$$i_{g2} = 1076\ (0.062) + (440 - 32)\ [0.35 + 0.5\ (0.062)]$$
$$\therefore i_{g2} = 222.16 \text{ Btu/lb.}$$

Then, $\triangle i_g = i_{g2} - i_{g1} = 222.16 - 44.37 = 179.79$ Btu/lb.

If (L_1) is the rate of the cold water as it enters the tower, in lb./hr, then on 1 lb. dry gas basis the water-gas ratio at the top end of the tower is obtained from the following heat balance:

$$(L_1/G + 0.0349)\ (130 - 32) - L_1/G\ (68 - 32) = 179.79$$
$$\therefore\ L_1/G = 2.8124 \text{ lb./lb.}$$

At the bottom end the ratio is:

$$L_2/G = 2.8124 + 0.0349 = 2.8473 \text{ lb./lb.}$$

Area of Cross-section

For 1-in. wooden grids (1 in. pitch × 1 in. deep × ¼ in. thick), selected for the purpose of this design, the number of velocity heads lost per ft of the packing height, as given by Carey,[6] is $n = 9$.

At the mean temperature of 257°F, the gas density is

$$\rho = \frac{20}{359} \cdot \frac{492}{717} = 0.0382 \text{ lb./cu.ft.}$$

From economic considerations, the optimal value of the gas rate is obtained from Equation (5).

$$G_E = 15{,}700 \left[\frac{\rho^2}{n}\right]^{\frac{1}{4}} = 15{,}700 \left[\frac{(0.0382)^2}{9}\right]^{\frac{1}{4}}$$

$$\therefore\ G_E = 857 \text{ lb./(hr) (sq. ft).}$$

The flooding point rate may be found by means of the Lobo correlation, as mentioned already.

For the mean value of the water-gas ratio, $L/G = 2.83$,

the term $L/G \cdot \sqrt{\frac{\rho}{\rho_L}} = 2.83 \sqrt{\frac{0.0382}{62.2}} = 0.07$

If the specific surface of the packing is, $a = 24$ sq. ft/cu. ft and the fraction of free space = 0.75 cu. ft/cu. ft, then for a mean water viscosity of 0.7 cp from Fig. 99 (Reference 3) the ordinate is 0.11.

The gas flooding rate is then:

$$G_f = \sqrt{\frac{(0.11)\ (0.0382)\ (62.2)\ (4.17 \times 10^8)\ (0.75)^3}{(24)\ (0.7)^{0.2}}}$$

$$\therefore\ G_f = 1.440 \text{ lb./(hr) (sq. ft)}$$

The economic value represents then nearly 60% of the flooding rate. Although acceptable, the area will be based on a safer rate of 781.2 lb./(hr) (sq. ft). This corresponds to a cross-section of:

$$S = 64 \text{ sq. ft.}$$

There is no need for checking on the minimum wetting rate at such a close approach to the flooding point. As a proof, the wetting rate determined from Equation (1) is:

$$\frac{L}{S\ a\ \rho_L} = \frac{(2.83)\ (50{,}000)}{(64)\ (24)\ (62.2)} = 1.48,$$

which is well above the minimum of 0.85.

Evaluation of the Mass-transfer Coefficient

As a result of both theoretical and experimental studies, the following gas-film formula has been developed by Carey.[6]

$$K_g = R \cdot \frac{C}{p_f} \cdot \left(\frac{P \cdot V_g}{d^{0.25}}\right)^{0.75} \qquad \ldots\ldots(22)$$

The terms have the following meanings:

P = total pressure (atm);
p_f = mean partial pressure of the non-diffusing component of the gas mixture (atm);
d = equivalent diameter of the gas passage (in.);
V_g = relative velocity of gas and liquid surfaces (ft/sec.);
C = a constant; and
R = enhancement factor.

The constant C varies only negligibly with temperature, and for water-gas systems its value is 0.7.

The enhancement factor R, being a function of the geometric shape of gas passages, has to be determined experimentally. For 1-in. wooden grids its design value may be taken equal to 4.2.

The following is the evaluation of the terms required for Equation (22).

$$\text{d} = 4 \times \text{mean hydraulic depth} = 4 \times \frac{\text{fractional free space}}{\text{wetted area}}$$

$$d = 4 \times \frac{0.75}{24} \times \frac{1}{12} = 1.5 \text{ in.}$$

Superficial velocity of the gas at its mean density of 0.0382 lb/cu. ft is

$$V = \frac{50{,}000}{(64)\ (0.0382)\ (3600)} = 5.68 \text{ ft/sec.}$$

Taking 0.5 ft/sec. for the liquid surface velocity (this is a conservative assumption),

$$V_g = \frac{5.68}{0.75} + 0.5 = 8.1 \text{ ft/sec.}$$

For operation at normal pressure,

$$(P \cdot v_g)^{0.75} = (1 \times 8.1)^{0.75} = 4.8$$

$$P_f = \left(1 - \frac{p_g + p_w}{2}\right) = 0.95$$

Substitution in Equation (22) gives

$$K_g = 4.2 \times \frac{0.7}{0.95} \times \frac{4.8}{(1.5)^{0.25}}$$

$$\therefore\ K_g = 13.7 \text{ lb./(hr) (sq. ft) (atm.)}$$

Evaluation of the Transfer Area

The gas, entering the tower at the temperature of $t_{g2} = 440$°F and with a humidity of $H_{g2} = 0.062$ lb./lb., is in direct contact with water leaving the tower at $t_{w2} = 130$°F. Since the saturated humidity of the gas at 130°F is $H_{w2} = 0.16$ lb./lb., the gas will undergo humidification until a section in the tower is reached where the reverse process (i.e., dehumidification) will have taken place. The two methods described in the foregoing discussion will now be used to evaluate the transfer area.

(a) The Graphical Method

With reference to the temperature-humidity plot (see Fig. 3), the point (a) represents the condition at the bottom section of the tower where $H_{ga} = H_{g2}$, and $t_{ga} = t_{g2}$. The co-ordinates of the (a') point are then $t_{wa'} = t_{w2}$, and $H_{wa'} = H_{w2}$. The (a-a') line, which represents the trend in the initial change of the gaseous mixture due to simultaneous heat- and mass-transfer, may be followed for a short distance only. This gives point (b), arbitrarily selected at a temperature of 400°F. The corresponding humidity, as given by the ordinate of the point (b), is $H_{gb} = 0.075$ (lb./lb.).

On the basis of 1 lb. of dry gas, the amount of water vaporised and transferred between the two sections is $dH_g = H_g a - H_g b = 0.062 - 0.075 = 0.013$ lb. (The minus sign indicates the direction of the transference.) The new rate ratio is $(L/G)_b = 2.8473 - (-0.013) = 2.8486$ lb./lb. The temperature of water in equilibrium with the gas at section (b) can now be calculated from an enthalpy balance.

The enthalpies of the gas at the two sections are:

$$i_{gb} = 1076\ (0.075) + (400 - 32)\ [0.35 + 0.5\ (0.075)\ ]$$

$$\therefore i_{gb} = 219.64 \text{ Btu/lb.}$$

$$i_{ga} = i_{g2} = 222.16 \text{ Btu/lb. (calculated already).}$$

$$\therefore \triangle i_g = i_{gb} - i_{ga} = 222.16 - 219.64 = 2.52 \text{ Btu/lb.}$$

By enthalpy balance:

$$2.8473\ (130 - 32) - 2.8486\ (t_{wb} - 32) = 2.52$$

$$\therefore t_{wb} = 128.6°\text{F.}$$

Water vapour pressure at 128.6°F is $p_{wb} = 110.8$, and the corresponding saturated humidity is $H_{wb} = \dfrac{110.8}{760 - 110.8} \cdot \dfrac{18}{20} = 0.153$ lb./lb.

The new co-ordinates enable location of point (b'), giving thus rise to a new line (b-b'). The procedure is repeated until the top of the tower is reached. The results are given in the tabulated form, together with the calculated driving humidities $(\triangle H) = H_g - H_w$, and their reciprocals. From the tabulated data the plot of H_g vs. $(1/\triangle H)$ is prepared (Fig. 4) and the graphical integration carried out.

The area under the two curves in Fig. 4 is:

$$\int_1^2 \frac{d\,H_g}{\triangle H} = 5.74$$

The transfer-area, as calculated from Equation (9), is therefore:

$$A = \frac{G}{K_g} \cdot \frac{M_w}{M_g} \cdot \int_1^2 \frac{d\,H_g}{(\triangle H)}$$

$$= \frac{50{,}000}{13.7} \cdot \frac{18}{20} \cdot 5.74$$

$$\therefore A = 18{,}850 \text{ sq. ft.}$$

(b) The Enthalpy Method

With reference to Fig. 1, the enthalpies, which have been calculated already, are:

$$i_{g1} = 44.37 \text{ Btu/lb.}$$

$$i_{g2} = 222.16 \text{ Btu/lb.}$$

$$\triangle i_g = i_{g2} - i_{g1} = 179.79 \text{ Btu/lb.}$$

$$\therefore i_{gm} = \frac{i_{g1} + i_{g2}}{2} = 133.26 \text{ Btu/lb.}$$

The saturated enthalpies of the gas, corresponding to the three points of the equilibrium line, are now found as follows:

At $t_{w1} = 68°$F, the absolute humidity is $H_{w1} = \dfrac{17.5}{760 - 17.5} \times \dfrac{18}{20} = 0.0212$ lb./lb. and the corresponding enthalpy,

$$\therefore i_{w1} = 1076\ (0.0212) + (68 - 32)\ [0.35 + 0.5\ (0.0212)\ ]$$

$$i_{w1} = 35.40 \text{ Btu/lb.}$$

At $t_{w2} = 130°$F, $H_{w2} = 0.16$ lb./lb., and

$$i_{w2} = 1076\ (0.16) + (130 - 32)\ [0.35 + 0.5\ (0.16)\ ]$$

$$\therefore i_{w2} = 213.20 \text{ Btu/lb.}$$

Similarly, at the mean temperature of $t_{wm} = 99°$F, the saturated humidity is $H_{wm} = 0.0602$ (vapour pressure at 99°F = 47.6 mm), and

$$\therefore i_{wm} = 89.30 \text{ Btu/lb.}$$

$$Y_1 = i_{g1} - i_{w1} = 44.37 - 35.40 = 8.97 \text{ Btu/lb.}$$

$$Y_2 = i_{g2} - i_{w2} = 222.16 - 213.20 = 8.96 \text{ Btu/lb.}$$

From Equation (17):

$$Y_m = i_{gm} - i_{wm} = 133.26 - 89.30 = 43.96.$$

From the chart of reference 7, for $\dfrac{Y_m}{Y_1} = \dfrac{43.96}{8.97} = 4.9$, and $\dfrac{Y_m}{Y_1} = \dfrac{43.96}{8.96} = 4.9$, the factor $f = 0.622$.

From Equation (18):

$$(\triangle i)_m = f\,.\,Y_m = 0.622 \times 43.96.$$

$$\therefore (\triangle i)_m = 27.3 \text{ Btu/lb.}$$

Using Equation (21), the transfer area is:

$$A = \frac{G}{K_g} \cdot \frac{M_w}{M_g} \cdot \frac{(i_{g2} - i_{g1})}{(\triangle i)_m}$$

$$= \frac{50{,}000}{13.7} \times \frac{18}{20} \times \frac{(222.16 - 44.37)}{27.3}$$

$$\therefore A = 21{,}300 \text{ sq. ft.}$$

as compared with 18,850 sq. ft obtained by the graphical method. This is in agreement with our previously-made statement, that the assumption of unity for "Lewis number" introduces a safety factor when dealing with gases lighter than air.

Height of Packing

For 1-in. wooden grids the specific surface is $a = 24$ sq. ft/cu. ft. The cross-sectional area of the tower has been established already at $S = 64$ sq. ft. Taking the higher value of the transfer area, $A = 21{,}300$ sq. ft, the height of packing would be $Z = \dfrac{21{,}300}{(24)\ (64)} = 13.9$ ft, as compared with 12.3 ft on the graphical method basis.

With some overcapacity the height of the packed section will be fixed at:

$$Z = 15 \text{ ft.}$$

Pressure Drop

At the mean superficial velocity of 5.68 ft/sec., the velocity head is $\dfrac{v^2}{2g} = \dfrac{5.68^2}{64.4} = 0.5$ ft. The number of velocity heads lost through the 1-in. wooden grid packing is $n = 9$, per ft, then the total loss is $15 \times 9 \times 0.5 = 62.5$ ft of the gas. At the mean density of 0.0382 lb./cu. ft, this corresponds to $62.5 \times 0.0382 = 2.4$ lb./sq. ft or 0.47, say 0.5 in. H_2O. In estimating the power requirements the losses in other parts of the cooling tower system would have to be known.

Summary of Design

A tower of 64 sq. ft cross-section filled with 1-in. plain wooden grids to a height of 15 ft is required. The pressure drop through the packing is estimated to be 0.5 in. H_2O. The cooling water should be supplied at the rate of 235 gal./min.

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INDIRECT HEATING AND COOLING SYSTEMS — WITH SPECIAL REFERENCE TO THE MANUFACTURE OF SILICONES

By D. J. I. DAVIES and D. C. ROOTS

THE temperature limit beyond which the use of steam is usually regarded as uneconomical in heating systems is somewhere in the region of 400°F. Above this temperature, if direct heating is impracticable, an indirect-heating medium other than steam is employed. In the design of an indirect-heating system, one of the first decisions which has to be made is whether to use a liquid or a vapour system. A vapour system would normally be employed if the heat user consists of a single vessel which can be arranged at a sufficiently high level above the heat generator to return the condensate to the heat generator by gravity, thus obviating the need for a circulating pump. If, however, cooling is required as well as heating, then a circulating pump is usually necessary; there is a strong argument in favour of using the simpler liquid heating and cooling system. If there is more than one heat user and any or all of these require heating and cooling, then the argument in favour of employing an all-liquid indirect system becomes very much stronger. The plant described in this article is a good example of this; there are several heat users of varying types, each requiring heating and cooling and automatic temperature control.

Ring Main and Loop Circuits

Fig. 1 illustrates a typical Hygrotherm system with automatic control of both heating and cooling. The heat-transfer medium in the Imperial Chemical Industries' Silicones Plant at Ardeer was, until recently, tetra aryl silicate 180; it has now been superseded by T.A.S. 190, which is more stable at higher temperatures. The properties of T.A.S. 190 are given briefly in Table 1.

The heat-transfer medium is circulated through the heat generator (Fig. 1) by means of the circulating pump. The ring main includes the Hygrotherm patented vapour separator, expansion tank and condense system which will be described later.

Each heat user is placed in a loop circuit with its own loop pump, cooler and automatic control equipment. Control of the batch temperature is obtained under endothermic or exothermic conditions by automatically varying the temperature of the circulating medium. Two 3-way valves are arranged for split-phase operation so that when the controlled temperature is below the set point, hot liquid is admitted from the ring main; if the temperature is above the set point, the heat-transfer medium is directed through the cooler. When the controlled temperature coincides with the set point, the heat-transfer medium is fully recirculated and at intermediate positions of the valves there will be proportional flows in either of the two path combinations.

TABLE 1—T.A.S. 190 Heat-transfer Medium for Liquid-phase Heat Transfer without Pressure between 50°F and 675°F

Physical Properties

Temperature °F	Temperature °C	Viscosity (cks)	Specific Gravity	Inst. Cubical Expansion per °F × 10^4	Specific Heat* Btu/lb.°F
50	10	150	1.21	3.7	0.37
100	38	35	1.18	3.8	0.38
300	149	2.8	1.10	4.1	0.42
500	260	1.1	1.01	4.5	0.51
650	343	0.7	0.94	4.8	0.60

* Based on similar liquid.

Thermal conductivity: approx. 2×10^{-5} Btu/sec. ft °F.

The control system comprises two temperature transmitters, a two-pen receiver controller and two 3-way valves (A) with valve positioners. One signal—the batch temperature—is controlling and the other signal—heating medium temperature—is recording only. Thus it can be seen that the heat-transfer medium supplied to the heat user may vary from the temperature of the hot-ring main to the lowest temperature attainable by means of the cooler. In the plant at Ardeer the liquid in the ring main is normally at 300°C. Extremely fine and accurate temperature control is obtained by using this system owing to the comparatively small amount of heat stored in the medium in the loop circuit and the rapidity with which its temperature can be changed. For instance, on full heating duty the residence time of the liquid in the loop circuit is less than one minute. Temperature control to within ± 1°C has been achieved by using standard equipment.

Vapour Separation and Condense System

The heat-transfer medium used in this plant has a maximum operating temperature of about 350°C. During its operating life this liquid slowly decomposes and one of the products of decomposition is a mixture of low-boiling phenolic compounds. For some years it was considered that these low-boiling breakdown products should, as far as possible, be retained in the system in order to reduce the viscosity of the liquid, particularly when starting up from

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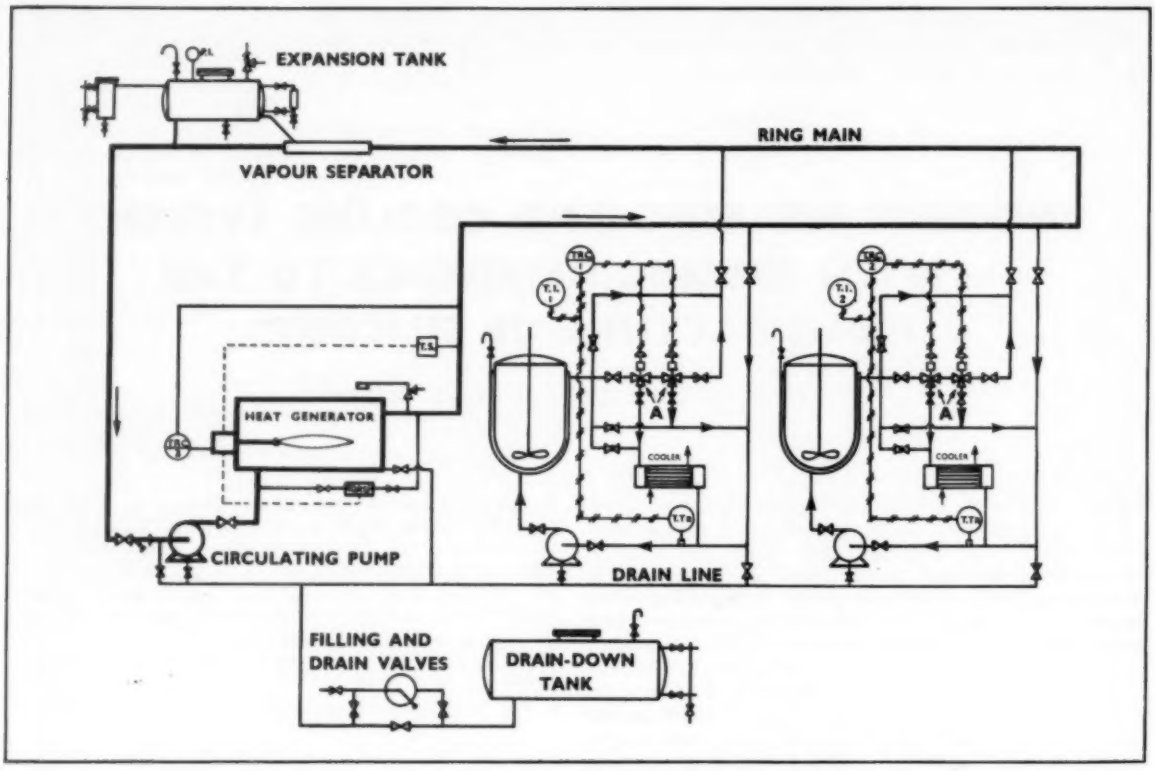


Fig. 1. Flow diagram of Hygrotherm system with automatic control of heating and cooling.

cold. Furthermore, it was considered that, according to the law of mass action, removal of these products would accelerate the decomposition reaction. However, observations of systems in operation over the past five years and research carried out have indicated that, as the proportion of low boilers increases, a stage is eventually reached when vapour locking and pump cavitation will occur, particularly during start-up from cold. An indication of the improved liquid life obtained in practice is shown by reference to the records of simple analysis before and after the new vapour separation system was installed in a representative plant. The first charge of T.A.S. has a useful life of over two years. The second charge was put in when the new vapour separator system was installed, and is still in excellent condition after nearly two years, and the analysis figures indicate that a further one to two years' useful life may be expected. This represents an improvement of approximately 50%.

The present Hygrotherm patent vapour separation system is designed with this object in view. The vapour separator (Fig. 1) is installed at the highest point of the ring main and as near to the pump suction inlet as is practicable. It is arranged in such a way that a secondary flow is set up in the expansion tank and the height of this expansion tank above the vapour separator is such that the lower pressure in the expansion tank causes low boilers to flash off and to condense in the condense vessel, whence they can be removed at regular intervals. The expansion tank is thermally insulated and the condense vessel is not insulated.

General Description of Silicones Plant

There are several different types of heat user in this plant. Some are of unconventional design and only those which are of particular interest will be described.

Glass-lined Jacketed Reaction Vessels and Stainless-steel and Mild-steel Jacketed Reaction Vessels. In each instance the jacket through which the heat-transfer medium is pumped is baffled with spiral baffles in order to improve turbulence. An interesting feature of glass-lined vessels is the fact that the degree of thermal shock to which the glass lining is subject during heating up and cooling down can be limited automatically.

A simple method of controlling the temperature difference during heating is illustrated in Fig. 2. The batch temperature and that of the medium entering the jacket are measured by means of two pneumatic temperature transmitters. The output from the jacket entering temperature transmitter is fed to one side of a differential bellows in a double-duty controller. The output from the vessel temperature transmitter is fed to the other side of the differential bellows and also to an ordinary bellows in the same

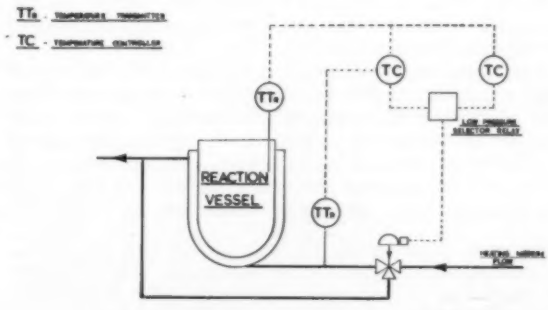


Fig. 2. Diagram of a simple method of controlling temperature difference in a glass-lined vessel.

instrument. The instrument can thus give two independent outputs, one proportional to the difference between the batch setpoint and the actual batch temperature, and the other proportional to the difference between the desired maximum temperature difference and the actual temperature difference. These two pneumatic outputs are fed into a pneumatic relay which selects the lower pressure for transmission to the operating valves. A slightly more complex system is available for systems having automatic control of both heating and cooling.

TILTING MIXERS. These are Baker Perkins type incorporators. In order to provide the maximum degree of turbulence in the jackets, these are baffled. Rotary joints are used to facilitate the tilting action of the mixers and to avoid the use of flexible tubing. The inlet and outlet connections are coupled via a "jack knife" or "scissors" system having a rotary joint at each pivot. The joints revolve on internal ball-bearings to ensure accurate alignment and the glands are packed with soft copper washers. The temperature-measuring element is a temperature transmitter which has the advantages of requiring only a short immersion depth and convenient flexible air-line connections. The viscous nature of the product in the mixer prohibits the use of a long temperature-measuring element, due to the substantial forces developed at the point where the temperature is measured. The heat load is fairly steady and a single-term temperature recorder is used with an additional recording pen so that a record is given of the temperatures both of the contents of the mixer and of the heating medium entering the jacket. The controlled temperature is that of the heating medium because, as is well known, it is almost impossible to obtain a truly representative measurement from within the mix and it is necessary to control from the medium temperature by empirical means.

BATCH DISTILLATION UNITS in which the heating medium is circulated through a heating coil. The temperature of the heating medium is controlled by a single-term pneumatic recorder controller.

HEAT GENERATOR. The Hygrotherm heat generator in this plant is situated in the open (as shown in Fig. 3). The main part of the heat generator is of weather-proof construction and only the oil-firing equipment needs protection. The heat generator is specially designed to obtain the maximum heat flux compatible with long liquid life. This is achieved by rapidly circulating the liquid and avoiding hot spots or stationary pockets where there would be a possibility of damaging the liquid. Maximum use is made of direct flame radiation and the amount of refractory material is kept to a minimum. The overall size of the unit is comparatively small. Maintenance charges are very low for a number of years. The oil firing is controlled by a fully automatic modulating control system including automatic start-up and protective devices against flame failure, over-temperature and circulation failure.

Fig. 3. A patented oil-fired heat generator externally mounted, providing heating service to part of I.C.I.'s silicone plant at Ardeer. Also shown is the system: drain-down tank, vertical stack and two circulating pumps (one stand-by) with connections to the overhead ring main.

In a heat generator for this type of application, the efficiency is limited by the high temperature of the fluid being heated, since the temperature of the flue gases must be higher than the temperature of the indirect heat-transfer medium. The difference in temperature between the flue gases and the fluid being heated is governed by the economic size of the convection section. In the Hygrotherm heat generator the use of a generous radiation section combined with a moderate size of convection section has allowed reasonable efficiency to be attained whilst at the same time ensuring the avoidance of high heat-transfer rates at any point in the heater.

CIRCULATING PUMPS. The main circulating pump and stand-by are situated in the open, since the pour point of T.A.S. (−20°F—A.T.S.M. D97/39) is well below the lowest temperatures likely to be encountered in winter; no arrangements are necessary for steam tracing. The motors are sized to start up from cold in winter. In this particular plant the pumps are manufactured by Rhodes, Brydon & Youatt Ltd., and are of cast-steel/stainless-steel construction, the packings used being Veemet "C" alternating with braided mica plastic. Recent tests with mechanical seals have proved successful and these pumps can be fitted, if necessary, with water-cooled mechanical seals.

Safety Course for Executives

A TWO-DAY symposium for executives and professional people on safety and health in plant planning and layout, recently held in Birmingham, marked the start —reported to be notably successful—of a new development in the activities of the Industrial Safety Training Centre, Summer Road, Acocks Green, Birmingham, 27. Directed by an architect, the symposium included lectures by H.M. Inspector of Factories, consultant engineers and public health officials, and its syllabus covered legislation relating to effluents and other matters; the use of heating and ventilating plant; storage and handling dangerous materials; reducing danger from dust and fumes; and fire precautions. For the second symposium, which will be held on October 16 and 17, most of the 27 places are already taken and the Centre advises early application for the remainder.

The Centre is thought to be the only one of its kind in the world, and it is organised by the Birmingham and District Industrial Safety Group, a voluntary body which, as its chairman (Mr. P. B. Whitehouse) said at a ceremony recently, is "supported entirely by the modest subscriptions from Midland industries and charges fees that only just cover costs". He was speaking at the celebration of the completion of the first full year's programme at Acocks Green. During the year, more than 1400 students attended safety courses for, among others, chemical workers, part-time safety officers and engineering apprentices.

THE CHEMICAL ENGINEERING EXHIBITION

A preliminary survey of some trends and innovations at this Exhibition, the first of its kind ever to be staged in Great Britain

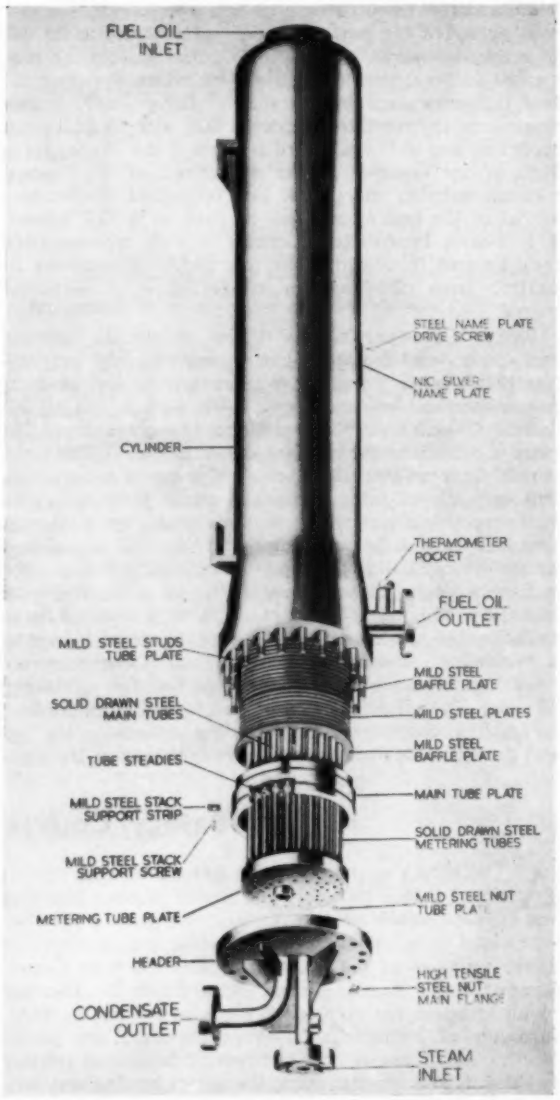
RESTRAINT and diffidence usually typify the statements made by British engineers and scientists about their own achievements, a virtue which has at times placed this country at a commercial disadvantage compared with its competitors. The Exhibition now at Olympia is the first of its kind ever to be held in this country and demonstrates in a decisive manner the abilities in design and manufacturing technique possessed by that section of British industry which produces processing plant; the presence of actual designs or their small-scale counterparts emphasises much that normally remains either undisclosed or unheralded. The engineering skill which has contributed so much to the rapid development of the petrochemical and chemical industries during the past thirteen years is faithfully reflected in the exhibits. It is evident that, in addition to a mass of first-class ancillary equipment, the industry can also produce complete manufacturing plants such as oil refineries and petrochemical installations.

Working Models

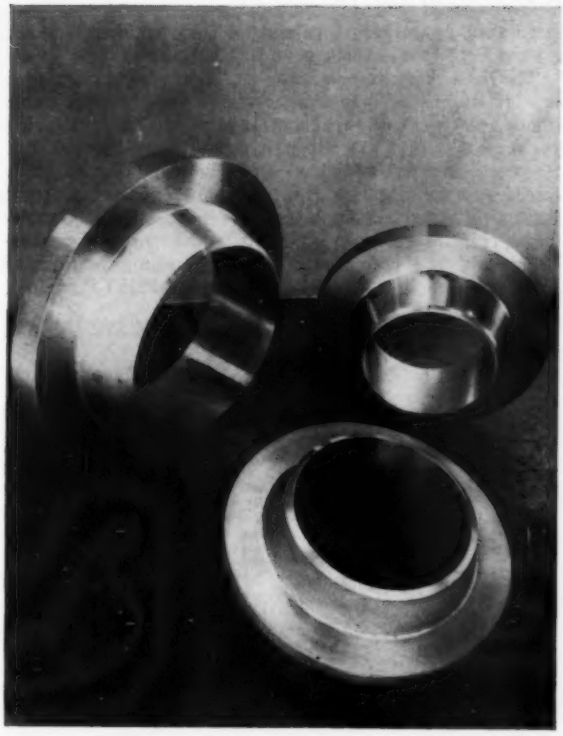
A variety of important process principles is illustrated by means of working models, which are not only attractive to the uninitiated but provide a convincing demonstration of the soundness of the designs themselves. To add to the general interest, a number of small items of processing plant, including mixers and ancillaries such as pumps, are shown at work.

The growth of the fluids-solids technique is reflected in some of the models. The application of the general principle to drying processes is represented on the F. W. BERK stand by a new drying machine using the fluid-bed principle. Along with this machine, there is a more conventional design wherein the solid material is conveyed along with the drying air. A transparent model using the same principle and handling wet feed is the well-established T.V. drier shown on the KESTNER stand. Among the pump demonstrations is yet a further example making use of the fluidising principle. This particular exhibit shows solids being pumped liquid-wise through a system of transparent piping; the pumping is carried out by means of a Mono pump and a very small quantity of compressed air is injected to produce the fluidised condition.

Crystallisation—a subject with a great visual appeal—is illustrated by the POWER GAS CORPORATION with their working model of the Krystal unit. There are examples of working models which show processes of such diverse nature as water cooling (HEAD WRIGHTSON PROCESSES) and continuous mixing (STOCKDALE ENGINEERING). To add to the variety there is a perspex model of a heat exchanger, normally made in carbon, to be seen on the POWELL



Among the many examples of heat exchangers on show at the Exhibition is the Serck GF furnace-fuel oil heater shown above.



Selection of Firth-Vickers Stainless Steels Ltd.'s centrispun weld neck flanges which are suitable for many of the applications which, until recently, necessitated the use of the forged variety. One such application is that of the coupling of pipes.

A working model of a Wiggins gasholder on show at this Company's stand at the Exhibition.

DUFFRYN stand. Showing the *modus operandi* of the cubic exchanger; a little dramatic flavour is introduced by the same company's demonstration of bursting discs in action. The solution to the problem of conveying highly viscous fluids or semi-solids is offered by GEORGE FLETCHER, who show their stainless-steel rotary pumps (Amarilla); shown in operation transferring heavy viscous materials.

Whatever the commercial gain through these working models may be, if they succeed in stimulating interest in the underlying technology they will have served a useful purpose.

Complete Processes

Compared with the makers of individual units of plant, the manufacturer of complete process plants is at a disadvantage in an exhibition, since his products can only be shown in model form and by flow diagrams and photographs. Despite this disadvantage, a great deal can be appreciated from the exhibits devoted to complete processes.

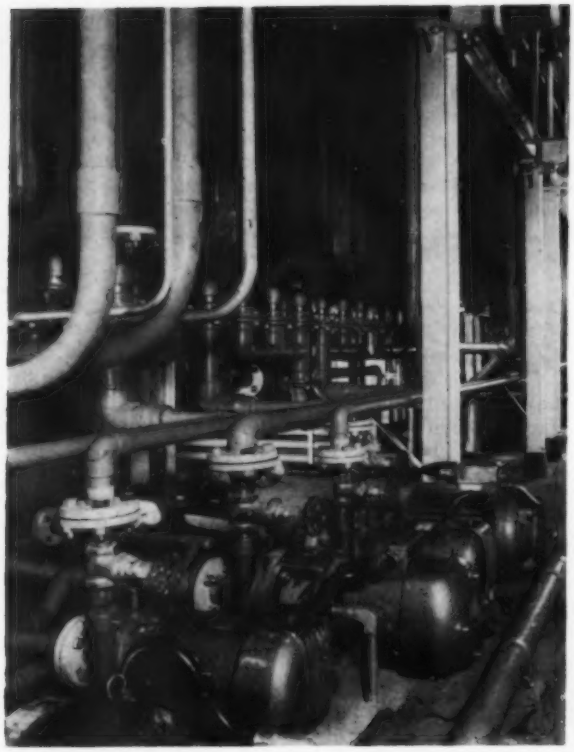
An example in the low-temperature field typifying the developments in the nuclear power programme is a heavy water plant shown in model form by PETROCARBON DEVELOPMENTS LTD. In this process deuterium is separated from hydrogen by distillation at −283°C; combustion with oxygen then yields heavy water. Cold in this process is produced by expansion turbines and a high-purity feed for distillation is obtained through a combination of regenerators and reversing heat exchangers. Also representative of the low-temperature field are the BRITISH OXYGEN and the BRITISH OXYGEN LINDE COMPANIES with their tonnage nitrogen and oxygen plants and units for the manufacture of rare gases.

The manufacture of anhydrous hydrochloric acid (important to the technology of chlorinated plastics, such as PVC) by the combustion of the elements is the principal subject of the BRITISH ACHESON exhibit. They show an entire full-scale plant constructed of impervious graphite for carrying out this process wherein the hydrochloric-acid gas produced at the graphite burners is absorbed to give a strong aqueous solution. This, on evaporation, gives the constant boiling mixture and a wet gaseous product from which the anhydrous acid is eventually obtained. The water is removed in two stages of condensation, the first employing water as the coolant and the second brine.

Besides these samples of the capabilities of the firms manufacturing complete processes, the visitor should not overlook the nuclear power plant model, itself a reflection of a great scientific and engineering advance, shown by SIMON CARVES; the model of the revolutionary hydrogenation gas-making plant to be erected by HUMPHREYS & GLASGOW at Partington; and, finally, a further example along with the model of the Dido reactor shown by HEAD WRIGHTSON PROCESSES.

Distillation

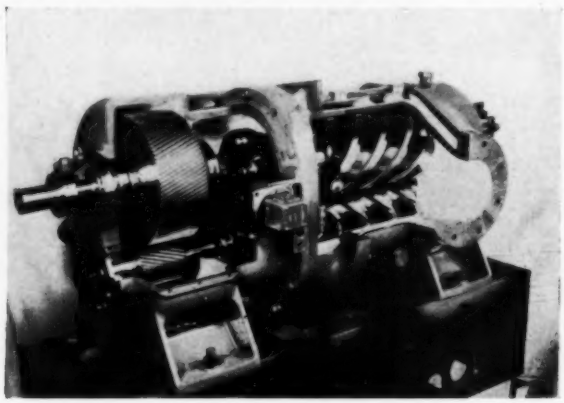
In addition to the many examples of conventional distillation equipment shown by A.P.V., METAL PROPELLERS and other companies, from Switzerland comes an unusual small-scale device, the Kuhn Precision Distillation Column shown by SULZER. For gas-liquid contacting, this employs a nest of vertical tubes with the liquid flowing filmwise downwards and the vapour upwards through the tubes. Very low H.E.T.P. values and low-pressure loss characterise the performance of this column; conditions close to the adiabatic are obtained through a jacket surrounding the column attached to an auxiliary reboiler. Unusual though it may be as a material of construction for distillation columns, stoneware is used by HATHERNWARE for a column of 1.4 m diameter. This vessel is of the bubble-cap type,



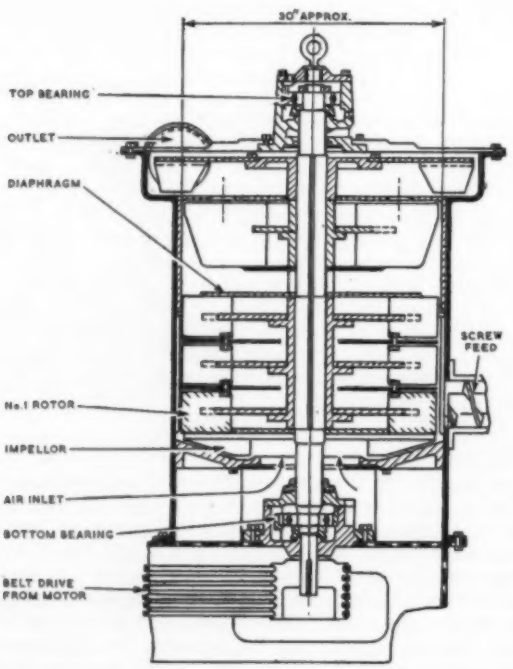
Pipework installation using parts made of styrene-butadiene copolymer. Incledon, the manufacturers, also fabricate in nylon and Zeigler polythene.

it is armoured and its associated equipment, including a circulating pump, pipework and lubricated plug valves, are all made of stoneware.

The need of modern technology for tower packings with low resistance to gas flow and with higher allowable liquor rates than is possible with Lessing or Raschig ring packings is met by the HYDRONYL SYNDICATE by their Pall rings and Intalox saddles. A novelty for small-scale work introduced by this company and developed by BRITISH OXYGEN RESEARCH & DEVELOPMENT is the BORAD double-gauze ring. Made from either stainless-steel or phosphor-bronze gauze, these rings allow equilibrium conditions to be reached rapidly and have very small H.E.T.P. values.



The highly efficient, oil-free rotary compressor by James Howden uses helically fluted rotors. Output: 800-8500 *cfm to* 60 *psig single-stage;* 150 *psig two-stage.*



Cross-sectional annotated diagram of a Russell fluid energy mill showing the operating parts in detail. Some idea of the dimensions of this fluid energy mill may be gained by the approximate diameter measurement given at the top of the above diagram.

Pall rings figure also among the gas-liquid contacting devices shown by WEINREB & RANDALL. The display includes Slot-wall rings and KnitMesh Multifil; the latter packing combines high surface area with high voidage and H.E.T.P. values of 1 in. to 2 in. may be attained with it in small columns. In common with many of the newer contacting devices, this one also allows high throughputs with low pressure loss.

Grinding Equipment

Fine grinding in the micron ranges is a field which has developed noticeably in this country in recent years. At the Exhibition, in addition to a few fluid energy designs basically of American origin, e.g., the "Jet-o-Mixer" (KEK LTD.) and Microniser (F. W. BERK), there are two other designs of grinding machinery which merit close attention. First there is an outstanding high-frequency vibratory mill shown by WILLIAM BOULTON. Close control of the grinding process without contamination of the material being ground, compactness and outstandingly low power consumption are some of the advantages possessed by this design over the conventional ball mill.

The second design is a fluid-energy mill differing from its competitors in a number of respects. Instead of using energy derived directly from compressed air, it relies upon the action of high-speed subsonic air waves to bring about size reduction, and like other fluid energy mills its attainment in this direction is well in the sub-sieve range. This mill, shown in section in one of the illustrations to this article, makes use of a stage system of impellers separated by diaphragms and housed in a fluted cylindrical body. The difference in pressure set up on either side of a diaphragm as the solid-bearing air is conveyed from one stage to the next causes each diaphragm to vibrate with

a sound energy in excess of 120 dB over a wide range of frequencies. The design is flexible and the number of stages may be varied to suit whichever application may be called for.

Fabrication

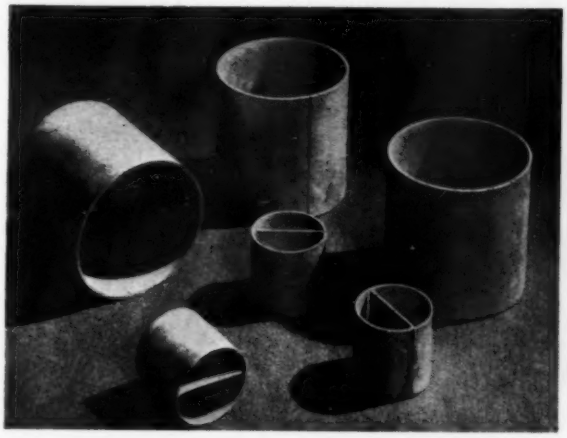
Not only is there on show at the Exhibition a range of plant and ancillaries by means of which almost any process could be operated, but there is also a selection of equipment valuable to the plant maker and erector.

A number of examples of fusion welding techniques are presented; the submerged arc method, which has proved highly successful in pressure vessel fabrication, is demonstrated on the LINCOLN ELECTRIC stand. On the same stand, actual demonstrations will be given of a compressed air-carbon arc cutting and gauging process for stainless steel, monel and other exotic materials. Welded components, however, are not the only ones required by the various processing industries, a point brought out by the equipment exhibited by SHEEPBRIDGE ALLOY CASTING LTD. This company offers cast components in a number of special materials such as Nimocast and the British equivalents of the Hastelloy and Illium alloys. The large, centrifugally-cast tubing produced by this company also should not be overlooked.

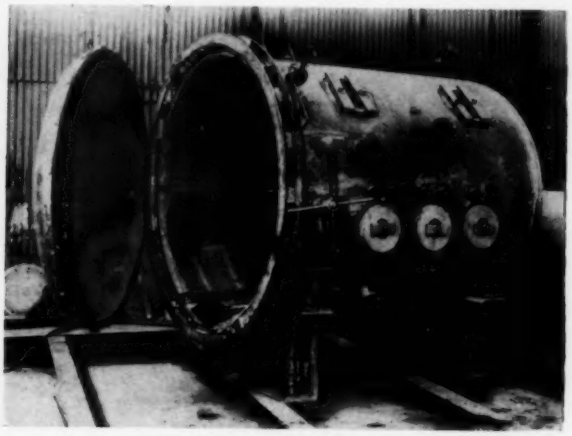
Mention of materials which originate from the HAYNES STELLITE CORPORATION would not be complete without reference to the DELORO STELLITE exposition. One of its centres of attraction is the demonstration of a new method for applying a surface of cobalt-base stellite alloy to components for protection against corrosion, wear and heat; the technique shown uses a flame-spray gun. Valves handling abrasive and corrosive fluids may have their inner surfaces treated in this way. An attraction, apart from the spectacle of the process in action, is the fact that visitors can bring along small articles for treatment. In addition, small samples will be available for those who wish to give the coatings a trial.

Yet another important fabricating operation to receive attention at the Exhibition, and one emphasising its broad scope, is the expanding of tubes into heat-exchanger tube plates. One interesting tool for this purpose shown by WICKSTEED & CO. is an expander torque-control unit which, used in conjunction with a portable electric-drill motor, gives a controlled expansion of heat-exchanger tubes.

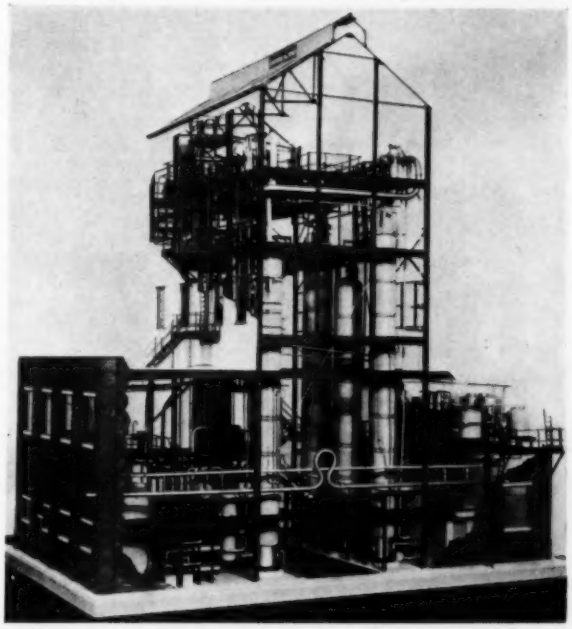
Finally, what can be done by the methods of fabrication now available to the plant maker is very well exemplified by the 14-ft diameter, double-cone, stainless-steel mixer made according to WILLIAM GARDNER's design (of Gloucester); similarly impressive is the all-welded vacuum pressure vessel shown by G. A. HARVEY. This vessel has a minimum wall thickness of $\frac{5}{8}$ in. and weighs over 23 tons. On the same stand is to be seen an unusual dished-end made from four pieces of $1\frac{1}{2}$-in.-thick stainless-clad mild steel. The diameter of this unit is 12 ft 9 in. and the material of construction (Colclad) is a product of COLVILLES LTD. The cost compared with an all 18-8 end would be interesting.



Tower packings in titanium for corrosive conditions are a product of Imperial Chemical Industries and are but one instance of the expanding use of this material



The ring clamp boltless door exhibited by Robert Jenkins & Co. Ltd., is a fine example of high quality construction.



One example of the service offered by the manufacturers of complete process plants is that of a model of the Beckton tar-acids distillation plant presented by the A.P.V. Co., to the Science Museum. This model has been loaned for display on the A.P.V. stand at the Exhibition.

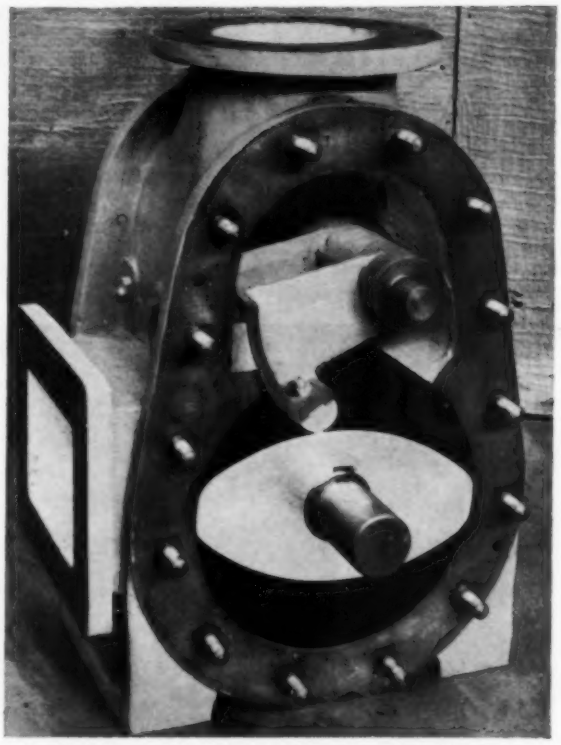
Plastics

Among the important trends reflected in the Exhibition is the growing use of synthetic materials for constructional purposes. At one end of a quite extensive range can be found such components as nylon-lined diaphragm valves as shown by WYNN VALVES, and valves of a similar type shown by SAUNDERS constructed from a styrene-butadiene polymer. For handling corrosive fluids both BARFLO and INCLEDON show pipework assemblies and fittings in a similar material, which has the advantage that components manufactured of it are readily joined by solvent welding.

The use of well-established materials such as PVC is also broadening, as is shown by the PVC rotary vacuum filter displayed by DORR OLIVER. Various examples of reinforced polyester type material show how important material of this type has become for processing equipment. It is not exceptional nowadays to find storage tanks constructed in this material of capacities of 3000 gallons or more. Its versatility is shown on the MENDIP stand by the presence of a Nutsch-type vacuum filter, some small processing vessels and a filter press plate. The use of glass-fibre laminate by HATHERNWARE, as an alternative to cast iron or mild steel for reinforcing chemical plant constructed from stoneware is another use out of the ordinary. Yet another example of what can be done with well-established materials is a pump constructed of asbestos-filled phenolic resin on the APPLETON & HOWARD stand. This material, of which several varieties are available under the trade name of "Ferrobestos" (J. W. ROBERTS), has proved very useful for a number of components of processing equipment which have to work under corrosive conditions.

Ancillaries

In addition to the main plant items, there is a formidable array of ancillary pieces of equipment ranging from steam traps to valves and pumps of all varieties. GIRDLESTONE, for example, show a range of self-priming centrifugals available in most of the common metallic materials of construction. Another noteworthy centrifugal is that of APPLETON & HOWARD which is suitable for filter press work. By incorporating a jet pump in the design, a characteristic is obtained which is impossible with the normal centrifugal pump, i.e., constant flow against variable head. In practice, filtrations carried out through this pump may well result in longer filter cloth life and better cake formation. With the design at present available, the maximum head attainable with a reasonable delivery is about 350 ft.



Front-end cover removed from an Amarilla rotary pump showing its interior construction and accessibility to the working parts of the pump.

Tower packings by Weinreb & Randall comprise stainless steel and chemical stoneware Pall rings and a wire mesh packing.

Maintenance

In view of the popularity of scheduled maintenance it is not surprising to find in this Exhibition some attention to this topic, and more than one exhibitor has shown an appreciation of the maintenance engineer's tasks. Pumps, often inevitable sources of trouble through the arduous duties thrust upon them, are now more frequently designed for easy replacement and inspection of their working parts. A case in point is the new range of flooded-suction centrifugal pumps introduced by BRITISH LABOUR for handling awkward fluids; for with pumps in this range impellers and their internal parts can be removed for inspection or overhaul without disturbing either the connection pipework or the prime mover.

Of a different mould are the various pieces of maintenance equipment. Also on view are tools for tube descaling and surface cleaning and—such is the breadth of this exposition—even pipe wrenches, albeit of an improved type, are on view.

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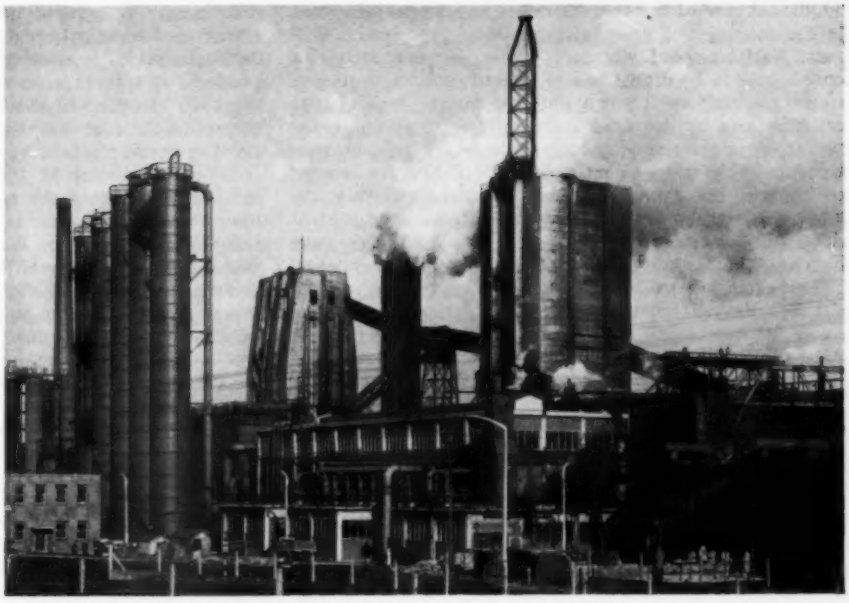


Fig. 1. General view of the coking plant showing, left, benzole scrubbers; centre, exhauster house; and, right, naphthalene scrubbers.

RECONSTRUCTION AT MANVERS MAIN

A £9-million development scheme, now virtually completed, has made the Manvers Main Coking and By-products Plant of the National Coal Board the largest of its kind in the country

THE batteries of coking ovens at Manvers Main, Wath-on-Dearne, Rotherham, which the National Coal Board took over on vesting day, had worked under arduous conditions during wartime, and in 1949 a decision was made to rebuild the plant. The original carbonisation plant, started in 1906, had been modernised in 1934, when Simon-Carves commissioned a block of 30 underjet regenerative ovens together with a new by-product plant. A year later a further block of 15 ovens was added, and that total installation was vested in the Board.

In the recent rebuilding programme, severe site restrictions necessitated, first, careful planning to make the best use of available ground, and, second, progressing the reconstruction stages according to a strict plan. It was the Board's policy to design for flexibility in operation, to ensure that the products could always meet the current demands of the markets, and a further design problem was that of integrating the existing plant with the new extensions into one complete unit. The whole project was complicated by the fact that the plant had important gas commitments to outside consumers which necessitated the rebuilding being undertaken without altering at any time the normal throughput of just under 1000 tons of coal a day. Continuity of output was achieved by adopting the following three-stage plan:

Stage 1: A completely new battery of 17 compound underjet regenerative ovens was built on the end of the 15-oven battery. Stage 2: The 15-oven battery was demolished down to pad level and was rebuilt as rich-gas-fired ovens. Stage 3: The remaining block of 30 ovens was split into two sections, three chambers being converted into a mid-buttress and a block of 13 ovens rebuilt as rich-gas-fired ovens.

Coal was fed to the batteries during the reconstruction by bridging, one bridge being used throughout to accommodate the different lengths between buttresses. All the re-built batteries were equipped with dual collecting mains, individual to each block and with central off-takes, and the reconstruction scheme was completed in 1953.

Whilst the ovens reconstruction was in progress, a major colliery development scheme was being prepared. This involved the construction of a new central coal preparation plant on the Manvers site, underground combination of the Manvers, Wath and Kilnhurst collieries—the total output being wound at Manvers—and the overland transportation of the Barnburgh colliery output to the new plant. This central plant is the largest in Europe with an output of about 12,000 tons a day, of which 3000 tons is coking coal with a maximum size grading of $\frac{1}{4}$ in.

As a result of this concentration of output of coking coal within conveyor distance of the coke ovens, together with the favourable geographical position for gas disposal and the potential saving in capital to be effected by utilising existing plant and combined services, a scheme for extending the carbonising capacity to 3000 tons a day became a logical outcome. The site was far from ideal for such an installation. The Midland Region main line from North to South cuts the site into two halves, and the curved link line between the Midland and Eastern Regions completes the intersection. Nevertheless, the overall economic advantages of the total project were considered to more than outweigh site difficulties.

The coal preparation plant consists essentially of three separate units, each treating a different rank of coal—high, medium and low in coking value. Thus three bands of coal are fed separately to the blending bunkers. An

additional row of bunkers has been added and integrated to the existing two rows, giving a total capacity of 6000 tons. Variable-speed vibratory feeders serving each row enable coal to be drawn in any desired proportion to give either one uniform or two different blends, which, after crushing, can be delivered independently to either of the two main bunkers serving coal to the two blocks of oven batteries. This arrangement permits flexibility, for one set of batteries could produce blast furnace coke, while the other could carbonise a blend producing an industrial or domestic coke depending on the markets. The coke handling plant is laid out to deal with such an eventuality.

The extension to carbonising capacity on the original site was limited not only by site restrictions but by the fixing of the oven dimensions by the existing plant. Accordingly, the 14 oven chambers left redundant from the reconstruction programme were re-built as rich-gas-fired ovens, and an additional block of 12 new compound ovens was added at the extreme end remote from the service bunker. Thus there are now 71 oven chambers in five separate blocks, giving a total throughput of approximately 1420 tons a day, the old ovens being completely integrated with the new to form one complete unit. To handle the increased volume of waste gases from the ovens, a new 250-ft chimney was built on the centreline of the ovens batteries. The waste-gas system was then changed over, and the old stack was demolished, leaving room for extensions to the ram machine track. New oven machines were provided, duplicating those in use.

New Ovens Batteries

The completely new installation of ovens batteries, as distinct from the extensions already referred to, consists of two batteries of 33 compound ovens in each, with all ancillaries. As there were no machinery restrictions, the oven chambers are larger than those on the existing site, having 28 heating flues per wall as against 24, and giving a total throughput of approximately 1570 tons of coal a day. To recover valuable ground space, the ram machine track is elevated on reinforced concrete columns and beams, and this structure has been panelled with red brickwork for housing welfare facilities for the workmen, the electrical sub-station and maintenance workshops.

Two complete sets of oven machines are provided, made to continental design and incorporating the latest improvements. Door cleaning lifts fitted with heat shields to protect the operators are built-in on both the ram and coke guide machines. The travel motions of the ram machines are equipped with Microsen gear which enables the machines to be centred quickly and with an absence of vibration. Fluid-flywheel drives and totally-enclosed lubricated gearboxes produce a smooth and quiet action. Compressed-air motors are fitted to extract the ram beam from the oven chamber in the event of electrical failure. The chassis of the coal-charging cars is mounted on the three-point suspension principle, which evens out the load.

Self-sealing doors of the Simon-Carves Woolf pattern are used throughout the plant. A new type of latch gear has been fitted to those of the 66 ovens batteries and of three of the batteries on the old site, its main feature being that the pressure between the sealing faces is exerted entirely by the weight of the door. Two toggle arms pivoted to the door body engage with the latch hooks, and the weight of the door acting through the toggle arms forces the sealing strips on to its facing. The advantage is that the closing force is constant and cannot be exceeded, thus avoiding strain on the latch hooks and sealing strips.

On the coke-handling plant all three wharf conveyors converge at the main junction house, from which dual conveyors transport the coke on separate systems to the main coke screen house. With the increased production from the extended plant—of the order of 2100 tons coke per day—it was decided to convert the existing primary screen house into a main junction house, and convey all coke up to a new screening plant on the opposite side of the main line, thus enabling the extended sidings facilities to cover both coke and coal traffic. The flow of coke throughout the entire plant is controlled from a centralised control desk fitted with a visual mimic panel.

By-product Plant

The old items of by-product plant equipment have been largely retained and integrated into the final layout. This plant, working on the indirect system of ammonia recovery, treats gas from three of the five individual blocks of oven chambers on the old site, and comprises, in flow order, primary vertical water-tube condensers, turbo-exhausters, electrostatic tar precipitators, grid-packed ammonia and benzole scrubbers. On the new site, there is a centrally situated by-product building housing the exhausters and compressors, with an extension on the end forming a substructure on which the primary condensers and detarrers are carried. The various pumps, covering water, liquor and tar services, are housed underneath this substructure, making a compact unit.

The turbo-exhausters deal with the gas output from two of the five batteries on the old site, as well as from the new batteries of 66 ovens. This system of by-product

Fig. 2. By-products section and coke ovens.

Fig. 3. Gas purification plant.

recovery is semi-direct, the gas flow comprising primary vertical water-tube condensers, turbo exhausters, electrostatic tar precipitators, gas heaters and saturators for ammonia recovery, secondary coolers and grid-packed benzole scrubbers. A new Wilton concentrated ammonia liquor plant, built to replace the old one, is located on the new site. Both the indirect and semi-direct ammonia stills are served by a single liming plant. Fig. 2 shows the final layout. Both gas streams combine after the benzole scrubbers on each side and the total volume surplus to underfiring requirements is then led to the gas-handling plant. Complete replacement of the gas-handling equipment was carried out as part of the extension scheme.

The gas-handling equipment in flow order comprises naphthalene washers, gas blowers, producers for dilution purposes, oxide purification plant, purified gas holder, boosters and after coolers. The producers, purification plant and purified gas holder are all located on the power plant site. The purification plant is shown on Fig. 3 and it may be seen that there are six working towers with two stocking frames, handling facilities being fully mechanised. Each tower contains thirteen trays of iron oxide and are the largest built by W. C. Holmes Ltd., being 29 ft 6 in. internal diameter and 71 ft high. A prototype plough will be used for unloading the spent oxide.

So that the existing supply of approximately 3.5 million cu. ft a day of crude gas to local industries can be maintained, the gas flow is split immediately after the naphthalene washers. Two 4-million boosters, one as stand-by, deal with this load and the original gas holder, of 300,000 cu. ft capacity, has been retained and integrated into the system as a balancing holder on the crude gas. The remaining volume after purification and dilution is dealt with by four machines of 6 million cu. ft per day capacity. To permit the required rates of steam consumption as against power consumption to be obtained, two of the six boosters are electrically driven, one steam driven and three are dually driven. The dual-drive boosters have double-ended shafts coupling to the steam engine or motor V-belt drive, and removable register plates so that connection can be made to one or the other as required. The motors are of the constant-speed type and are housed in a room separate from the booster section, the extension shafts passing through gas-tight boxes in the dividing wall.

Sufficient ground space has been reserved to cover the installation of producer gas plant for underfiring the compound ovens. In addition, provision has been made for extra gas-handling equipment to deal with the increased surplus of rich gas.

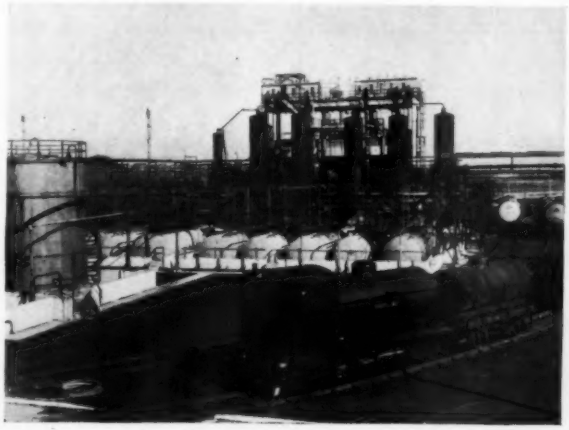


Fig. 4. Benzole rectification plant.

Integration of Benzole Plants

The old arrangement for the recovery and production of benzoles consisted of a crude benzole plant housed in a building with two once-running stills and columns. Benzole washers, pure stills and ancillary equipment were situated outside, immediately adjacent to the benzole house. Modifications to this section comprised the dismantling and removal of all equipment with the exception of the crude plant. The recovered ground space was then used to accommodate the additional crude benzole recovery units which deal with the benzolised oil from the scrubbers on the new site. Thus, once again, the original equipment has been integrated into the extended recovery plant.

The new benzole rectification plant (Fig. 4) has a total capacity of 5 million gallons of crude per annum, and is sited to the north of the main plant and about ¼ mile distant from it. The plant is provided with its own services, administrative and laboratory block, light repair shop, fireless loco for shunting, etc. Certain items of existing equipment were reinstated on the new site together with three new 10,000-gallon stills, de-fronting columns, benzole washers, etc.

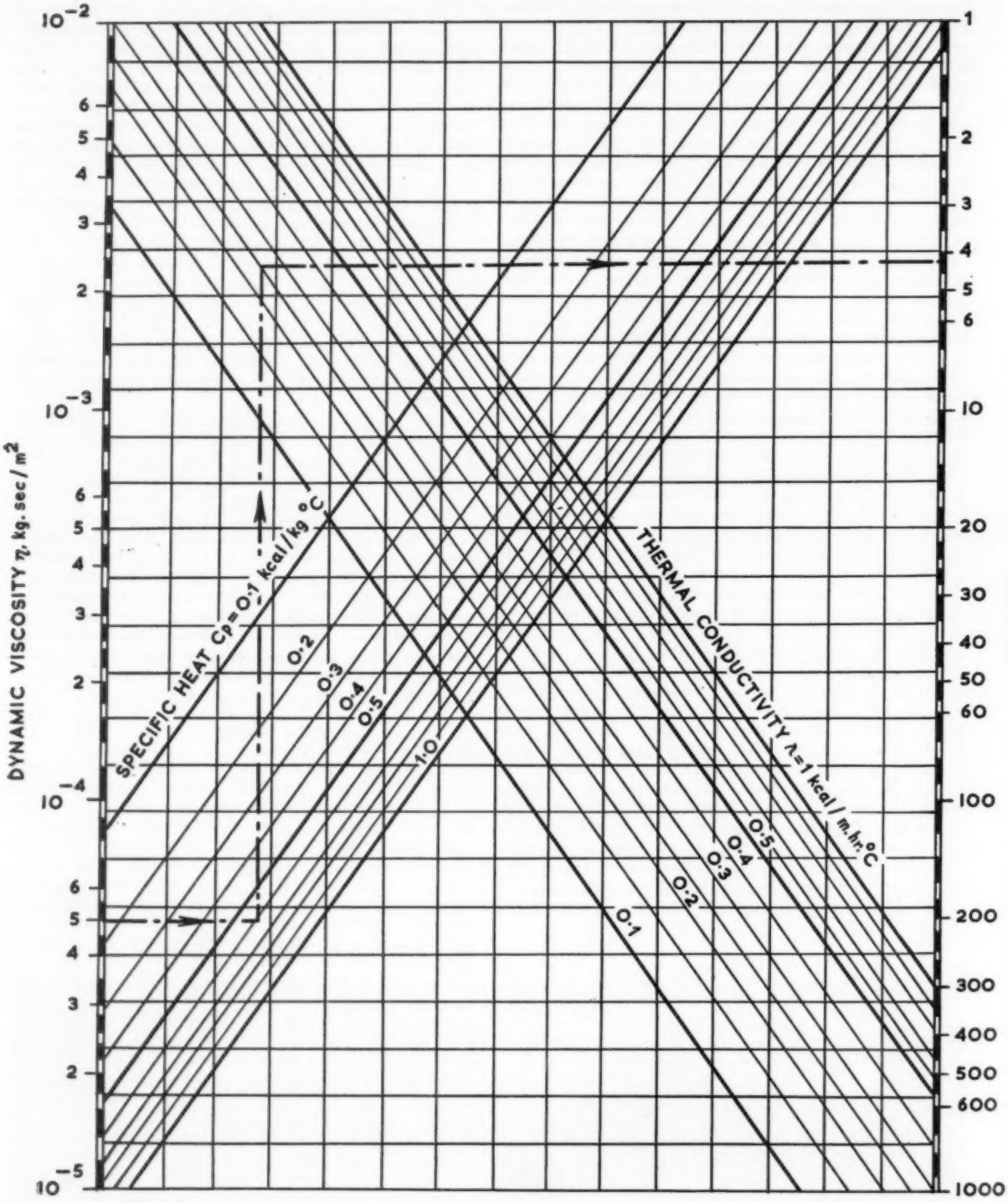
Crude benzole from the primary plant is pumped across to reception tanks at the refinery, where provision is also made to receive crude supplies from outside sources. The benzole is defronted, washed with once-run acid and then distilled in the primary stills. These produce semi-pure products which are washed again with concentrated acid before re-distillation in the secondary stills. The primary stills are operated semi-continuously, but the secondary stills are worked batch-wise. The distillation columns operate on the pumped reflux system and are designed to make a wide range of pure products; for example, three grades of pure benzene of different specifications are normally made, together with pure toluene, pure xylene and solvent naphtha. The plant is fully instrumented, and controllers are used wherever appropriate.

Power Station

The extended plant now has its own self-contained steam and electric plant supplying all requirements and, in addition, some steam is exported to the colliery. The water-treatment plant deals with the requirements of the coke oven plant and the boiler plant, filtered water being used as make-up for the closed-circuit cooling water system. All raw water is drawn from the River Dearne. Three Simon-Carves tri-drum, twin-circulation-type boilers, two normally working, one stand-by, and each rated at 60/70,000 lb. steam an hour at 625 psi and 815°F, use as fuel a sandwich of 90% coke breeze and 10% coal, provision also being made for burning coke-oven gas when surplus to Gas Board requirements. All prime movers on the coking plant for gas exhausters, boosters, pumps, etc., are driven by this medium-pressure steam, and exhaust at 15 psi into the L.P. system, which is finally used in process stripping-stills. The balancing effect on the rates of power to steam generated is effected by the availability of either electric motor or steam engine on the dual-driven gas boosters. By utilising both the sensible and latent heat content of the steam in this manner, the over thermal efficiency of the station is very good.

One result of the flexibility that has been built into the plant is that, if the 95 compound ovens (out of the total of 137 ovens), are fired with producer gas, the coke-oven gas liberated for outside use would be increased from 20 million cu. ft to 32 million cu. ft a day. In this respect, the N.C.B. are investigating the possibilities of installing slagging producers, which would utilise an inferior type of fuel at present being made available in increasing quantities at the central coal plant.

NOMOGRAM FOR CALCULATING THE PRANDTL NUMBER



$$Pr = 3600 \frac{c_p \eta g}{\lambda};$$

where c_p = specific heat of fluid;

η = dynamic viscosity $\left(\frac{\text{centipoise}}{98.1 \times 10^2}\right)$ kg sec./m²; and

λ = thermal conductivity k cal/m hr °C.

Example:

Fluid viscosity = 0.5 centipoises

$$= \frac{0.005}{98.1} = 5.10^{-5} \text{ kg sec./m}^2$$

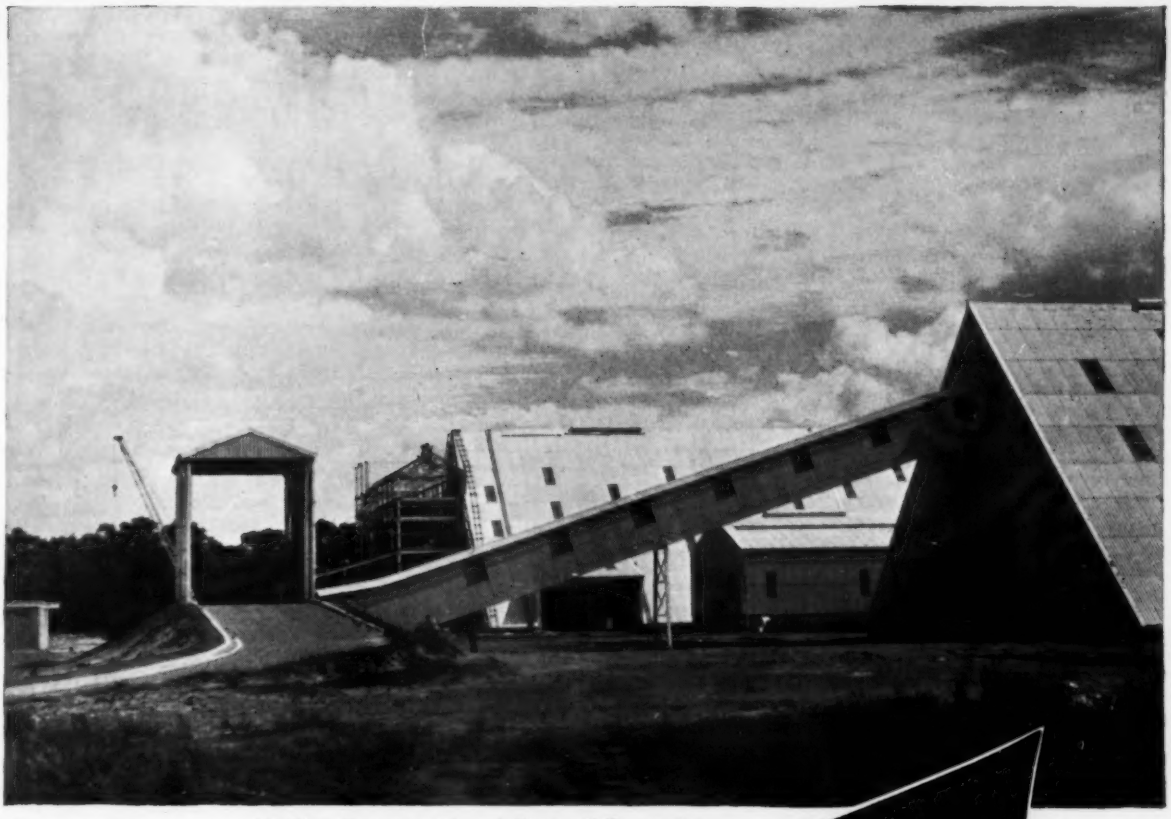
$c_p = 0.6$

$\lambda = 0.25$ k. cal/m hr °C.

From the procedure shown by the dotted lines, the value of Prandtl Number (Pr) is found on the right-hand scale = 4.23.

British Chemical Engineering

NOMOGRAM NO. 26



No. 6 *of a series*

Fertiliser Factory at Bay of Plenty, N.Z. nearing completion.

CHEMICAL & PETROLEUM ENGINEERING EXHIBITION
OLYMPIA 18-28 JUNE 1958
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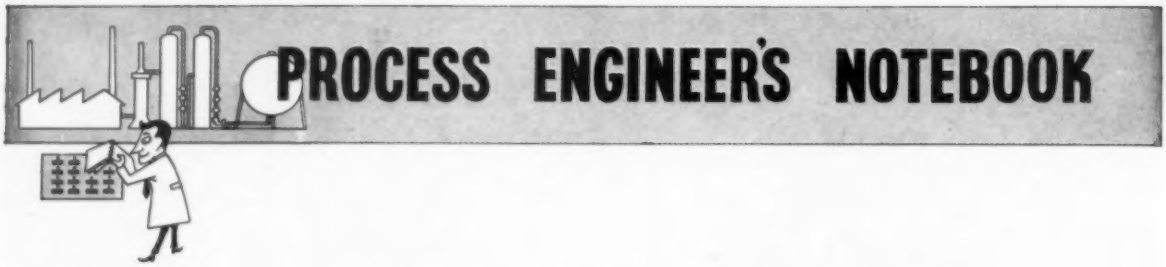
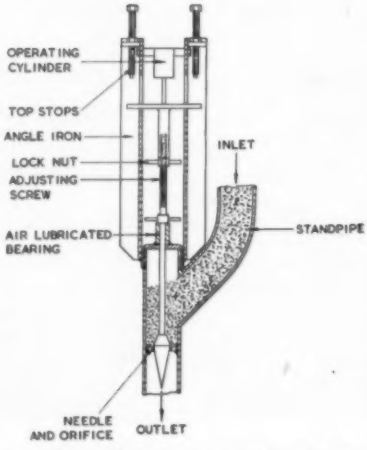


A New Valve for Controlling Flowing Powders

VALVES AT PRESENT used for controlling the flow of powders are notoriously unreliable and are subject to rapid wear and jamming of the moving parts. Many require considerable effort to operate them. This new valve has proved itself reliable even when handling abrasive materials at temperatures as high as 900°C. It operates smoothly, requires very little effort and over a period of two years the wear has been negligible. The design is shown in the accompanying diagram.

The rate of flow of solids through the valve is regulated by altering the effective area of an orifice by the movement of a conical valve head. As the surfaces of valve head and orifice are not in contact, alignment of these parts is not critical. This allows the bearing surfaces to be out of contact with the flowing powder. As a further precaution, an air bleed may be provided to keep the bearing free from dust. By adjusting the settings of the top stops and the effective length of the valve stem by the screw, the mean position and range of travel of the valve may be altered. In this way a simple on-off control system produces a continuous flow of powder which varies by only a small amount. Alternatively, proportional control may be obtained by suitable cylinders or diaphragm motors.



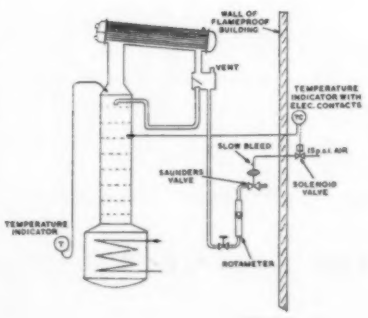
The materials of construction depend on the conditions of operation, but for temperatures up to 300-400°C mild steel and standard pipe fittings are suitable.

One type of valve which has been thoroughly tested was designed to operate at temperatures up to 900°C. The valve body and standpipe were made of standard 3-in. pipe fittings; the valve stem, head and seat from EN 58B, a common heat-resisting steel. With a 2-in. diameter orifice and a 4-ft standpipe, this valve controlled a flow of sand at rates up to 1 ton/hr against a pressure of 18 in. water gauge.

D. G. MADLEY
J. S. HARRISON

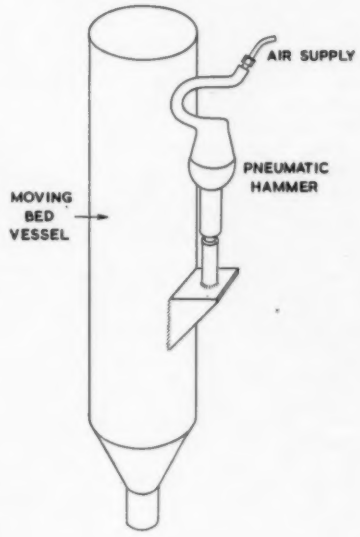
An Improved Method of Reflux Control

ANOTHER SYSTEM of reflux control for batch distillation columns similar to that shown in the March issue of this journal (page 159) is shown in the accompanying diagram. The main difference lies in the operation of the thermometer (fitted with the electric contacts) which controls the valve in the offtake line, whereas the valve in the reflux line remains permanently open. The actual offtake rate is, however, set manually from the position of a Rotameter float, and this, in turn, determines the reflux rate (with constant steam flow). As the composition in the boiler changes, occasional manual re-setting of the offtake rate will ensure that the increased reflux rate, required for satisfactory operation, is attained. This cannot be achieved so easily by the method of controlling the reflux valve as described in the March Process Engineer's Notebook. Also the method described here does not require the by-pass in the reflux line. The still in question is situated in a flameproof building, so that it was necessary to locate the thermometer head outside. It would, however, have been very inconvenient to position the control valve outside, and since this valve was required to be acid resistant, it was desired to avoid the expense of purchasing a flameproof stainless-steel solenoid valve. The thermometer contacts were therefore made to operate a small standard solenoid valve in a 15 psi compressed-air line. This valve was sited outside the building and the compressed air from it led to the actual control valve which consisted of a relatively inexpensive glass-lined Saunders valve with diaphragm operation (pressure to close). A small bleed in the air line was necessary to allow this valve to open when the solenoid valve closed. For better control, the bulb of the thermometer was placed one or two plates below the top of the column. In this way the on/off control will anticipate changes in top column composition, and thus reduce the time per batch during which the column operates under total reflux.



A Vibrator from a Pneumatic Hammer

SOLID GAS CONTACTING may often be satisfactorily carried out by means of the moving-bed technique. To maintain the solid particles in a moving-bed vessel in motion, some mechanical device is required such as a screw feeder. Sometimes vibrations ensure the requisite movement of solid material; the accompanying diagram shows how an improvised vibrator may be constructed from a pneumatic hammer. The hammer end is attached to a lug welded to the wall of the moving-bed process vessel. An application of the moving-bed method which made use of this improvisation was the pilot-plant oxidation of uranium tetrafluoride to the hexafluoride. The discharge rate of the solid particles was determined by the rotary speed of the discharge valve fitted to the base of the vessel (not shown in the diagram); the downward movement of the bed in the reaction zone was controlled by the rate of pellet discharge. Movement was ensured by the periodic supply of compressed air to the vibrator. For this purpose an electrical timer was used in conjunction with a solenoid valve.



Detecting Leaks in Vessels

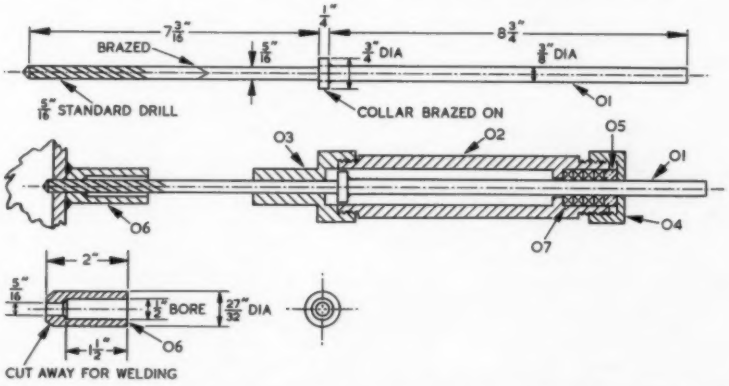
FOR DETECTING very small leaks in vessels, pipework and other processing equipment a number of methods are available. Some of them require very expensive equipment and others require no more than a "squeeze" bottle. Some methods use a tracer gas which is applied to one side of a vessel wall with a detector placed on the other side. Such a method was described in a recent paper by H. Kronberger ("High Vacuum Practice", *Brit. Chem. Eng.*, 1957, **3**, 1, 26).

Ammonia may be used as a tracer gas with the detector based upon brom cresol purple. At a *p*H of just below 5.0 the brom cresol ammonia causes the colour of this indicator to change from a pale amber-green to a deep purple. The method then consists of filling a vessel with ammonia gas at about 40 psig and applying the indicator solution with a brush over the suspected areas.

A suitable detecting solution can be made by dissolving 100 mg of the indicator in 10 cc of 0.02 normal caustic soda solution. This solution is then diluted to 250 cc; 50 cc of it are added to a starch slurry made up of 5 gm of starch and 250 cc of boiling water; a few cc of a wetting agent are then added to the slurry. Before applying the mixture to the surface of a vessel under examination, it is necessary to test the solution to make sure that it will be effective. This is done by dipping a piece of filter paper into the indicator and placing it in a horizontal position about a foot away from the open top of the bottle containing N ammonia solution. If the indicator is fit for use the colour change should be immediate; the vessel should not be tested until about 10 hours have elapsed.

Making Connections Without Interrupting Fluid Flow

THE DEVICE ILLUSTRATED in the drawings was designed to allow connections to be made to a steel pipe while a fluid (water) was passing through the pipe; an electric or compressed air drill may be used to operate the tool. Although a compression fitting-type valve is shown in the illustration, any screwed valve may be used, provided it is of the full-bore type. In this case, a standard coupling would be welded to the pipe and a standard nipple interposed between the coupling and valve; the end of the attachment would, of course, be screwed to suit the valve. If required, the soundness of the weld fastening the coupling to the pipe can be tested hydraulically before drilling is commenced. This device has been used successfully on water pressures up to 60 psig without any difficulty, and it would probably be equally useful for low-pressure piping systems carrying steam or other fluids.



F. WALKER

Contributions invited

THE EDITOR invites readers to submit, for possible publication in "Process Engineer's Notebook", notes on practical devices that have been elaborated on the job for improving the operation or increasing the safety of processes, or that have been extemporised in special circumstances. The contributions preferably should be of about 250-500 words, and be illustrated with a line diagram or sketch, or a photograph. A minimum of three guineas will be paid for each contribution used. They will be published anonymously or under the contributor's name, according to his wishes.

World of Chemicals

Expansion of Russian Chemical Industry

About £8900's worth of Russian capital (100,000 million roubles) are to be spent during the next seven years for "making equipment and for experimental work" in the chemical industry, Mr. N. S. Krushchev told the Plenary Meeting of the Central Committee of the Soviet Communist Party recently. He was presenting a report on speeding the development of the industry.

Manufacturing capacities would be increased as follows: for artificial and synthetic fibres, by 360%; for plastics and synthetic resins, eight-fold; and for synthetic rubber, by 240%. This would necessitate the bulding and reconstruction of 257 enterprises in the chemical and allied industries—the completion of 37 enterprises begun earlier, the erection and putting into operation of 120 new plants and the extension of 100 of those now in operation.

Many big plants would be built, Mr. Krushchev continued, in the Russian Federation, and in the Ukrainian, Azerbaijan and Uzbek Soviet Republics, which had a developed oil-refining industry or chemical industry, but the development would not be limited to these areas.

Dealing with the fabrication of chemical plant, he said that the "production base" of the chemical engineering enterprises would be greatly extended. Fourteen new plants would be built. Forty-two plants producing machinery for the chemical industry, for technological textile equipment for the artificial and synthetic fibres industry, and for armatures, compressors and pumps would be "erected and reconstructed". Plans were in hand to switch a number of engineering plants to the production of equipment for chemical engineering and to use for this purpose production capacities of the defence industry.

The successful development of the chemical industry, he added, necessitated the designing and introduction as quickly as possible of many new types of equipment. Special attention would be paid to designing automation equipment.

Stating that it would be advisable to order part of the equipment in the capitalist countries, and in the first place in the United States, Western Germany and Britain. Mr. Krushchev referred to previous successful engineering contracts placed with these countries. Russia was also ready, he said, to use the services of foreign scientists, engineers and inventors, as well as practical workers of other countries who could help them to carry out the tasks of increasing the output of plastics and synthetic fibres.

Developments in Nuclear Plant

A large new plant for converting uranium ore into metallic fuel elements for nuclear reactors is being built by the U.K. Atomic Energy Authority, and the chemical separation plant at Windscale is to be enlarged to provide a central fuel element processing facility for the whole nuclear power programme.

The two projects will enable considerable economies in the supply and processing of fuel elements for Calder Hall-type reactor furnaces to be achieved. The Calder Hall atomic power station is also to be used for a series of experiments into the behaviour of uranium fuel elements under higher heat ratings.

The atomic power plant at Shippingport, Pennsylvania, described by the U.S. Atomic Energy Commission as the world's first full-scale central station atomic power plant devoted exclusively to civilian purposes, was formally inaugurated by President Eisenhower recently, with the wave of a "neutron wand" at the White House. The plant has been in operation since last December, and has provided about 30 million kWh of electricity for civilian use in the Pittsburgh region.

Trial with Titanium Impellers

Titanium as a material of construction has solved a corrosion problem of the Calera Mining Co., U.S.A., that involved treating slurry in conditions which 316 stainless steels and other alloys could withstand for only a few hours. An impeller, air piping and slurry discharge piping fabricated in that metal recently completed a four-year service trial in the slurry almost unchanged. The plant was for leaching cobalt-arsenic-sulphide concentrates at pressures of 550-600 psig and at temperatures of above 400°F; the slurry contained cobalt, nickel, copper, arsenic, iron and sulphuric acid in solution, and iron-arsenic compounds in the solid phase, and the reaction was carried out in an acid-brick lined, horizontal autoclave, 6 ft × 40 ft. The protective liner for the flange covers on the various autoclave openings presented many problems, the company state, but sheet titanium served well and initial fabrication difficulties were lessened by altering the design.

Gas Grid Proposals

Proposals for a large gas pipeline linking London and Manchester and production and consuming areas *en route* were made by Dr. J. Burns, chief engineer, North Thames Gas Board, in his presidential address to the Institution of Gas Engineers' annual meeting in London recently. Within a belt 35 miles on each side of a line between London and Manchester there was used over 70% of the total gas produced in Britain, he explained. The belt also included an important oil importing and processing area at each end and more than 70% of the country's developed reserves of low-rank coal suitable for gasification.

A 30-in. main which would carry up to 600 million cu. ft of gas a day in one direction economically could link supplies from gas-from-oil plants at the two ends, large pithead coal gasification plants in the Midlands and outside sources such as coke ovens, he suggested.

New Oxygen Plants

The first tonnage oxygen plant to be installed by a gas board is to be erected at the North Western Gas Board's new hydrogenation plant at Partington, near Manchester, and it will be capable of producing nearly 63 tons of oxygen daily. The contract has been placed with Air Products (Great Britain) Ltd. by Humphreys & Glasgow Ltd., the main contractors.

British Oxygen Gases are building a new factory on a 25-acre site near to their factory at Polmadie, Glasgow. It will include a liquid oxygen plant, a compressing station and stores.

Oil Consumption in 1957

U.K. oil consumption declined by nearly 2% in 1957 compared with the previous year. This was the first time in ten years that demand fell below that of the preceding twelvemonth. Demand for fuel oil, however, increased by 7%. Total consumption of all products amounted to 24,736,541 tons.

Production of Mexican oil last year—12,600,000 metric tons — was slightly lower than in 1956 and had to be supplemented by imports.

Underground Shale Extraction

In an experiment to explore the possibilities of the underground extraction of oil from shale organised by the Ministry of Fuel and Power, Scottish Oils Ltd. are sinking bores to the deposit in Winchburgh, West Lothian, Scotland. It is proposed to ignite the shales and distil the vapours at ground level to produce crude oil for conventional refining.

Catalysts in Molecular Sieves

Union Carbide claim to have used for the first time molecular sieves as carriers of catalytic materials. They held a volatile liquid catalyst for curing vinyl silicone rubber so that it could be marketed in a paste form.

German Chemical Expansion

Fourteen to sixteen per cent of the turnover of Badische Anilin, Bayer and Hoechst will continue to be ploughed back, according to statements made recently by the chairmen of those companies. Investments of the German "big three" amounted to £75 million, last year, and a capital assets expansion of £70 million is expected in the current year. The companies have seen no sign so far of a recession, and their turnover during the first few months of this year was above the level for 1957. Most of the new plant will be situated in Germany, including the £25 million petrochemical installation of Bayer and B.P. and the £17 million expansion of the Badische and Shell plastics plant. However, Bayer, the most active company of the three in foreign investments, recently set up a $20 million holding company at Toronto, under the name Foreign Investments Ltd., and it intends to centralise there all or most of its foreign holdings.

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Book Reviews

Thermodynamics for Chemical Engineers
by Harold C. Weber and Herman P. Meissner (Second Edition)
John Wiley & Sons Inc., New York; Chapman & Hall, London, 1957, 507 pp., 68s.

ALTHOUGH this book is designated a second edition of an earlier "Thermodynamics for Chemical Engineers" by the senior author, H. C. WEBER, it is actually a new book. For a number of years the new text has been used in duplicated form by undergraduate and graduate chemical engineering students at the Massachusetts Institute of Technology, and is possibly the best book for teaching chemical engineering thermodynamics available today. However, the difference between British and American undergraduate teaching must be emphasised. The American method is to reduce the number of formal lectures to a minimum, and discuss difficult points and problems in informal seminars. A textbook, therefore, must explain its subject-matter in sufficient detail to be fully understood without using further references, and be written in readable English. This book fulfils both these premises. It is easily understandable by a reader who has only elementary calculus at his disposal.

The treatment of a number of fundamental topics may not appeal to some lecturers in British universities, but gaps can be filled by the lecturer during the course. When presenting a teaching text the author is faced with the difficult decisions of inclusion or omission, and here the emphasis has been placed on chemical engineering applications of thermodynamics. Examples of this are the treatment of flow systems under the heading of "open systems", and a guide to the perennial chemical engineer's headache—the estimation of heat capacities and heats of reactions. A set of rules is given for the first, and a list of bond energies and how to use them for the second. Entropy is introduced in a very understandable manner, as if the author realises the difficulty of the average student when first meeting this. Fugacity and activity are introduced late in the book, about three-quarters of the way, and are followed by their application to homogeneous and heterogeneous equilibria, solutions, phase equilibria and electrochemical effects. The clear presentation of these topics forms some of the best sections in the book. A largely qualitative treatment has been given to power cycles, engines, turbines and refrigeration. This is ample for chemical engineers, but inadequate for mechanical engineers. Worked examples are liberally distributed throughout the text, solving the problems connected with each topic.

One criticism must be directed at the treatment of compression of gases. This has been dealt with twice; once as "algebraic presentation of data" in a chapter on the properties of pure materials, and again under "generalised PvT relations". In the former the BEATTIE-BRIDGEMAN equation and a table of its constants are given, while in the latter treatment the reduced equation of state is discussed. The names of VAN DER WAALS, DIETERICI and others are given, but not their equations or a discussion of their theoretical significance. The name of O. C. BRIDGEMAN has been spelt "Bridgman", which leads to confusion with the author of the "Physics of High Pressure", P. W. BRIDGMAN. The virial form of the equation of state has not been mentioned, but is treated as a special approximate form of the BEATTIE-BRIDGEMAN equation, without a discussion of its basic nature.

A number of original references are given as footnotes, and the nomenclature used in each chapter has been appended to that chapter, shortening the hunt through up to six pages of symbols if these had been collected together. A large number of problems are appended to each chapter, but, in common with American practice, no answers are given. The reviewer has been assured that all the problems have been solved by the M.I.T. students and give reasonable answers.

The criticism of some details is not meant to detract from the great worth of this book. It should be invaluable to those reading for the associateship examination of the Institution of Chemical Engineers. Moreover, it will no doubt be the recommended text-book for undergraduate classes in British universities for some years.

W. STRAUSS

Proceedings of the Reactor Safety Conference, New York, October, 1957 American Nuclear Society — Atomic Energy Forum

IS is now self-evident that the evaluation of reactor hazards, the need for continuing research into safety and stability problems and an insistence on high-quality design must occupy a prominent position in the affairs of an atomic energy authority. The publication of Part I of the proceedings of the U.S. A.E.C. Reactor Safety Conference held in New York last October is of interest, since it coincides with the recent U.K. report on the reactor health and safety organisation of the U.K. Atomic Energy Authority (H.M.S.O., Cmd. 342; 1958). The U.S. and U.K. organisations are similar in that committee structures exist to provide the necessary safety clearance before reactor construction and operation can commence. In addition, both organisations possess Safety Research and Development Committees concerned with investigations into transient and stability problems, with the effects arising from reactor failure and the problems of fission product release and containment.

The conference proceedings describe the extent of experimental work in hand or planned by the A.E.C. A paper by HAMBREE ("A.E.C. Reactor Safety Experimental Programme") shows the emphasis given to the study of unsafe conditions in pressurised-water reactors (SPERT I, II, III, experiments), the problems associated with boiling water reactors (the KEWP experiment) and the considerable effort involved in safety experiments with fast breeder reactors (EBR, II, III and TREAT reactors). The conference also considered several matters of general interest in the chemical engineering field, one of which, the research programme into metallic pyrophoricity, is of interest to those concerned with developments in the use of rare metals such as zirconium and thorium.

The Reactor Safety Conference is undoubtedly a useful international forum, and the statement that the results of the U.S. safety research programme are to be unclassified as far as possible will be welcomed by those concerned with reactor development.

B.E.E.

An Introduction to Automatic Digital Computers
by R. K. Livesley
Cambridge University Press, 1957, 53 pp., 8s. 6d.

THIS BRIEF ACCOUNT of digital computers has been written mainly for engineers and others who are faced with tedious calculations so that they can judge the possibility of using these machines in their own numerical work. The author points out that preparing a normal engineering calculation for a digital computer certainly requires care and precise thinking, but does not usually demand great mathematical skill. The volume opens with a chapter on the elements of programming, then goes on to discuss input, storage and output of numbers. Following this is a chapter on the technique of organising programmes and finally methods of solution of engineering problems. The last section includes the intimidating but valid remark that the consequences of human incompetence are amplified rather than concealed by the speed of an electronic machine so that it is important that the human organisation built around a computer should be able to make the most of its potentialities.

Handbook of Chemical Data
Ed. by F. W. Atack
John Sherratt & Son, Altrincham, 1957, 629 pp., 36s.

THE FORMER "Chemists' Yearbook" edited by ATACK has now reverted to separate publication of tables of constants, as in its earlier years of publication. For this separate publication the present title "Handbook of Chemical Data" has been adopted. In compiling such reference works, there is always a problem of judgment involved in deciding what to include. In comprehensiveness this book, of course, suffers by comparison with the very much larger American compilations, but laboratories working on a limited range of subjects may find it more convenient to have this neat and compact—not to mention cheaper—volume available for frequent bench reference.

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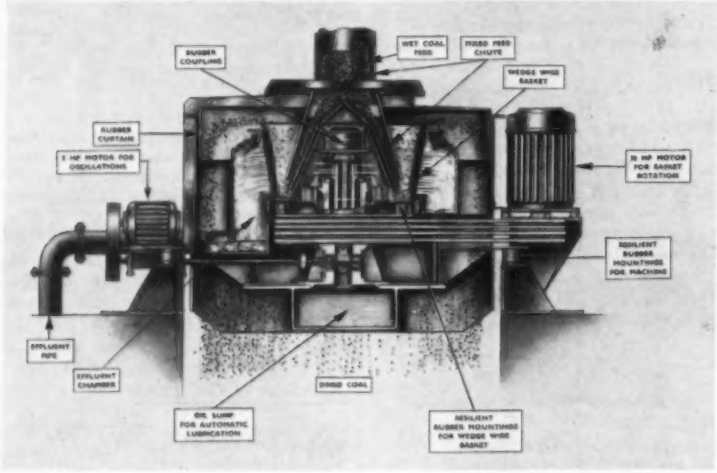
PLANT EQUIPMENT NEWS

Continuous Vibrating Centrifuge

A continuous vibrating centrifuge of a design novel to Great Britain is being made available in this country by the conclusion of a manufacturing agreement between Birtley Engineering and Klöckner-Humboldt-Deutz, A.G., of Germany. The main advantages claimed for the machine are lightness (the larger model, with a basket of up to 1000 mm in diameter, weighs 3.75 tons) and ability to work for long periods without attention. With coal, throughputs of up to 150,000 tons without changing the basket have been recorded, Humboldts state.

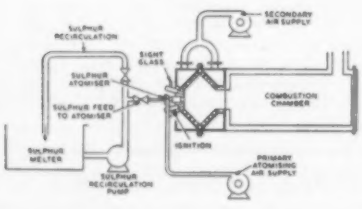


Its design centres on the basket of slightly conical shape. This spins on and is vibrated on a vertical axis, the drives for both movements being by belt from independent motors. The machine is adjusted so that, under the opposing effects of spinning and vibrating, the solid material creeps up the basket-side and is thrown over the top. The liquid passes through spaces of the wedge-wire basket-sides. The machine is rubber mounted and Birtley say that there is "little or no" transference of the vibration to the building. Power consumption is said to be below 0.2 kW/ton, and fine coal can be dewatered down to a 10% water content ±1%. Specially for chemical applications, a small model having a basket diameter of up to 500 mm is being manufactured. **Birtley Engineering Ltd., 32 Davies St., London, W.1.**

BCE 3457 for further information

Spray Sulphur-burner

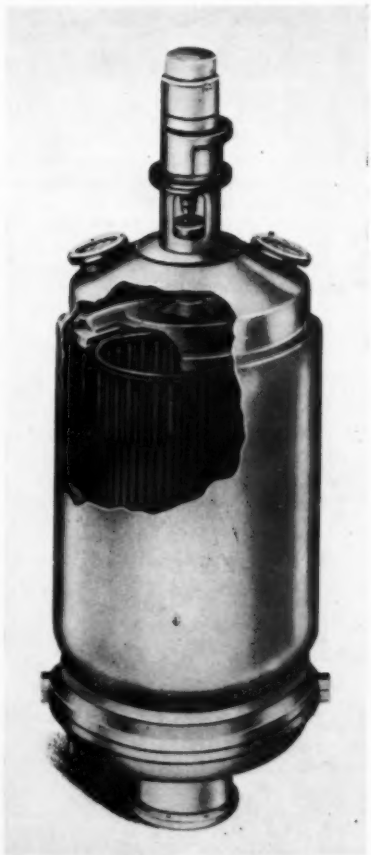
The new Kestner spray-type sulphur-burner has been developed to provide a high sulphur-dioxide concentration—a value of 18% being claimed for this—and a high turn-down ratio. Atomisation of the molten sulphur is effected by a hot air stream and this system allows wide variations to be made in sulphur throughput rate without shutting down to change the atomiser. The unit will operate against any back pressure normally encountered in the processing of burner gas, and it occupies little space. In its operation molten sulphur is continuously recirculated through the melter by a steam-jacketed pump. A continuous bleed is taken from the recirculation line through a jacketed pipe to the sulphur atomiser which injects the molten sulphur into the combustion chamber. At the same time, air from the primary blower is heated and fed to the atomiser. This primary air impinges on the sulphur jet, causing very fine subdivision of the molten sulphur. Secondary or combustion air is injected into the chamber at high velocity, setting up turbulence. Rapid combustion rates without the presence of excess oxygen are said to be obtained. The unit is available in sizes to handle from 1 cwt. up to 2 tons an hour of sulphur. **Kestner Evaporator & Engineering Co. Ltd., 5 Grosvenor Gardens, London, S.W.1.**



BCE 3458 for further information

Molecular Still

Now being made generally available is the Scott-Smith molecular still for the continuous separation or purification of materials, heat sensitive or of high molecular weight, under very high vacuum. The still is of a wiped and accelerated falling film design, a rotating wiper mechanism with detachable PTFE or carbon blades producing a thin, uniform but turbulent liquor film. The action of the wiper also accelerates the liquor film flow from top to bottom of the heated surface, so producing "very short" contact times. Within the still there are a finned tube condenser and a rotary entrainment separator, both concentric with and parallel to the heating surface. The condenser is arranged to give a short path flight of the molecules from the heating surface, and the separator is fitted to the rotating wiper mechanism so that it can be easily removed or installed. The vacuum is achieved by oil-vapour booster pumps normally backed by gas-ballasted oil-sealed rotary pumps, and the residual air pressure within the apparatus is reduced to 0.001 mm mercury absolute or less. The equipment is in use for processing—for example, vitamins, hormones, sterols, plasticisers, petroleum fractions and vegetable oils. **George Scott & Son (London) Ltd., Leven, Fife, Scotland.**



BCE 3459 for further information

8 new Sharples centrifuges

For years Sharples have offered the widest range of centrifuges. Now come no less than 8 new models. This means a still more impressive range which extends still further the scope of service that we can offer on all separational problems.

1 **MODEL P-600** A new cylindrical bowl pilot scale horizontal type Super-D-Canter with a 6″ x 14″ bowl—a larger version of the already popular P-400 Model.

2 **MODEL P-3000** A cylindrical long bowl horizontal Super-D-Canter extending the range of the P-1000 and P-2000 series. This unit has a clarifying capacity of up to four times that of the P-2000.

3 **MODEL P-4000** A completely new vertical type Super-D-Canter of large liquid throughput capacity, having a centrifugal force of 3100 x g. Designs available for operation at pressures up to 150 p.s.i.g.

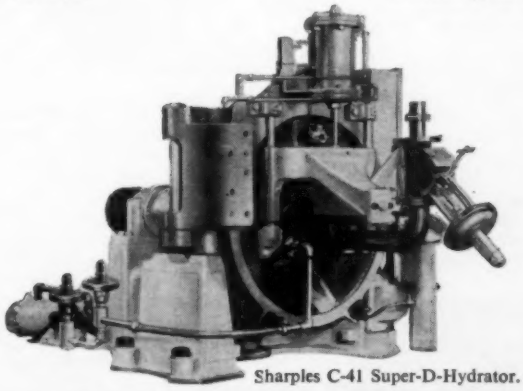
4 **MODEL P-7000** A larger vertical Super-D-Canter of solids handling capacity up to 10 tons per hour, with a centrifugal force of 1650 x g. Designs available for operation at pressures up to 150 p.s.i.g.

5 **MODEL C-41** A new high capacity perforate basket centrifuge of the Super-D-Hydrator range. Solids production capacity from 2-4 times that of the already well known model C-27 Super-D-Hydrator.

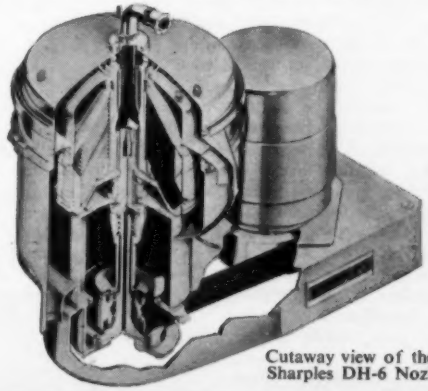
6 **MODEL DH-5** A new high capacity nozzle centrifuge having a liquid throughput of approximately twice that of the familiar DH-3 Nozljector. Designs available for operation at pressures up to 150 p.s.i.g.

7 **MODEL DH-6** The largest nozzle machine at present in our range, with a capacity of approximately 4 times that of the DH-3 Nozljector. Designs available for operating at pressures up to 150 p.s.i.g. The largest capacity nozzle centrifuge in the world !

8 **MODEL K-8** A pilot-scale Super Classifier for operation at feed rates of up to 250 lbs. an hour of dry powder. Suitable for test plant and for small scale production classification operations. Cut range identical with Super Classifier models K-16 and K-27.



Sharples C-41 Super-D-Hydrator.



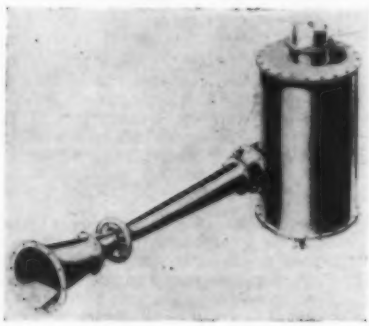
Cutaway view of the Sharples DH-6 Nozljector.

SHARPLES

PLANT EQUIPMENT NEWS

Gas Scrubbers

The Chemico Pease-Anthony gas-scrubbing equipment now being made generally available in Great Britain is used in the U.S.A. by many industries for the removal from gas streams of micron and sub-micron dusts, fumes, mists and fogs. It is made in two designs. In the cyclonic type dirty gas enters tangentially at the bottom of the scrubber and takes a spiral path upwards. Spray is introduced into the rotating gas from an axially-located manifold in the lower part of the unit, and the droplets are swept by centrifugal force across to the wall of the cylinder, colliding with and collecting the dust particles. The water and collected dust run down the walls and out at the bottom of the unit. Efficiences of above 99%, with small pressure losses and consequently low power requirements, are claimed for the equipment. Among applications for which the scrubber has been installed is the removal of lime dust from lime kiln gases, the recovery of lead compounds from reverberatory furnaces and the removal of ammonium nitrate from rotary dryer gases.



In the venturi type dirty gas at high velocity impinges on and atomises a curtain of liquid introduced through jets at the throat of the venturi. Mist or dust particles collide with the liquid droplets, and the coalescence of the unwanted particles makes simple cyclonic separation possible. A pressure loss of 10 to 15 in. w.g. is often ample for its operation. The equipment is being made available through licensing arrangements which have been negotiated recently between the Chemical Construction Corporation of New York and **Chemical Construction (Great Britain) Ltd., Bush House, London, W.C.2.**

BCE 3460 for further information

Vibratory Filter

A vibratory continuous filter is the latest piece of equipment to be added to Rhewum's range of Sonic machines. The filter cloth is suspended in a catenary curve, and vibrations are applied so that solids separated from the slurry form into a roll and are discharged over one side of the cloth. By adjusting the vibration and the in-flow, the self-filtering effect can be increased so that particles of which 75-78% would pass through the cloth are, in fact, retained. One end of the rectangular cloth is secured in the machine and the opposite end is agitated by the vibrator. In the direction of the agitation the cloth receives longitudinal vibrations which, however, become transverse towards the well of the cloth. Superimposition of these vibrations creates transport waves which form the separated solids into the roll. Rolling motion enhances the dewatering action, it is said, and the resulting product is practically a solid mass. **Rhewum, Rhemscheid - Luettinghausen. British Agent: John P. Barlow, 114 Wigmore Street, London, W.1.**

BCE 3461 for further information

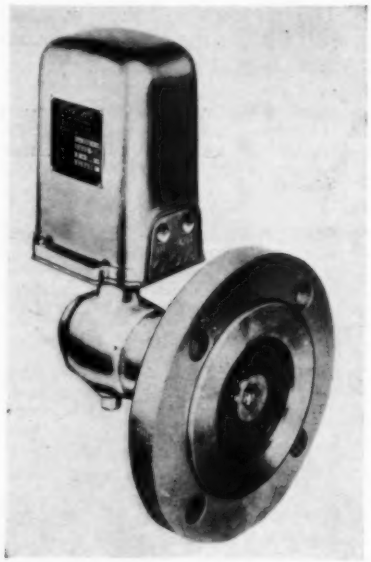
Components in Plastics

M.P. Components, a new wholly-owned subsidiary of Cawley Plastics, can supply, off the shelf, sheet and tube in unplasticised PVC, normal and high impact, and stubflange couplings in sizes ½ in. to 6 in. Each assembly consists of a stubflange machined from either high-density polythene or unplasticised PVC and an aluminium backing flanged machined to mate with the stubflange and drilled to B.S. Table "D". The stubflange is welded to the tube after first sliding the backing flange on the length of the pipe. After facing the end of the pipe and stub, the backing flange is brought up for bolting. The use of a gasket of Neoprene or flexible PVC is advised by the makers, and the machining allows for a slight protrusion of the plastic on to the gasket so that when two flanges are tightened a good seal is made. M.P. Components point out that with this type of coupling pressure is applied to the stubflange close to the tube, minimising the torque applied to the PVC flanges. Moreover, the backing flanges can be rotated to avoid difficulty in the alignment of bolt holes and the light weight of the couplings renders special support for the joint unnecessary. **Cawley Plastics Ltd., Wey Lock Works, Byfleet Road, New Haw, Weybridge, Surrey.**

BCE 3462 for further information

Liquid-Level Transmitter

Foxboro-Yoxall have added to their range of instruments a liquid-level transmitter, type 13FA, for mounting directly on the side of a vessel. It makes use of a force balance and is designed to measure liquid levels in open or closed vessels, and it transmits an output air signal to standard 3-15 psi receiver recorders and controllers which may be locally or remotely mounted. The sensing diaphragm is a flange mounted to the side of the tank. As there are no process piping problems, the instrument is particularly suited for the measurement of viscous fluids and slurries such as paper pulp, viscose and lime slurry. It is supplied in three forms; (a) with cadmium-plated mild-steel body and flange, diaphragm in stainless steel; (b) all in stainless steel; and (c) body flange and diaphragm in stainless steel with flange and diaphragm plastic-coated. **Foxboro-Yoxall Ltd., Redhill, Surrey.**



BCE 3463 for further information

Inspection Instruments

Vision Engineering are making available an instrument for the internal inspection of vessels and similar equipment. Named the Inspectascope, it is an optical device made to the design of a Mr. Robin Freeman, winner of a design competition organised by the *Daily Mirror*.

BCE 3401 for further information

JOHN THOMPSON PRESSURE VESSELS AND PROCESS PLANT

Illustrated above are two typical vessels, manufactured for the Petroleum Industry by John Thompson at their Dudley and Wolverhampton works. The top illustration is of a 56 ton, 88 ft. long steel tower, below is shown a 28 ton reactor vessel.

John Thompson were pioneers of fusion welding to Lloyds Class 1 standards in Great Britain, and are equipped to produce vessels for Chemical and Process Plant in mild and alloy steels to the highest standards. They offer to their customers a service backed by over one hundred years experience in pressure vessel manufacture and the resources of centralised group research laboratories in which methods of fabrication, metallurgical selection and testing are under continual development.

JOHN THOMPSON GROUP

JOHN THOMPSON (DUDLEY) LTD · DUDLEY · WORCS · ENGLAND

PLANT EQUIPMENT NEWS

It utilises a coaxial light system from a bulb fitted to the side of the inspection tube and reflected by mirrors on to the work. A range of sizes, all supplied with a power pack, is being marketed. **Vision Engineering Ltd., Send Road, Send, Woking, Surrey.**

BCE 3464 for further information

The new Ellispection industrial inspection kit comprises a series of rigid and flexible probes with fixed and movable mirrors, magnifiers and midget-battery-operated electric lights. All parts are interchangeable and interlocking. **Ellis Optical Co., Mayday Road, Thornton Heath, Surrey.**

BCE 3465 for further information

Vibrating Conveyor

A new range of natural-frequency vibrating conveyors is being made by Lockers, Warrington. Available in designs suitable for handling a wide range of materials from hot sinter to foodstuffs in dust-proof atmospheres, they require usually only one drive unit for every 200 ft of conveyor. The capacities and conveying speeds vary according to the application and the material being handled, but "several hundred tons an hour", it is said, can be conveyed at speeds of up to 90 fpm with drive units having 1-in. strokes operating at 470 rpm. Because of the low stresses imposed on the drive, weights in excess of 10 tons can be handled by also one drive unit. **Lockers (Engineers) Ltd., Warrington.**

BCE 3466 for further information

Rotary Vacuum Pump

The latest addition to the Metrovac range of rotary vacuum pumps is the type DR210, which comprises two single-stage, vane-type pumps mounted in a single oil tank and driven by a common shaft. The equipment, it is pointed out, has the pumping characteristics of two single-stage pumps with considerable saving in space. Operational noise has been kept to a minimum by the use of a quiet type of exhaust valve assembly and helical reduction gears. The pump provides a displacement of 1 litre/sec. at 370 rpm rotor speed for each section. The ultimate pressure is at 10 microns Hg. by McLeod gauge for each section. **Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester, 17.**

BCE 3467 for further information

Dust Collector

Prat-Daniel have developed a new dust collector unit, the Bahco wet cyclone, which, they point out, employs a new method of washing. The inlet branch, on entering the body of the washer, is immersed in a water bath so that the dust-laden air and water are sucked up by the vortex formed by the cyclone. The water is vaporised and an intense washing action is obtained with large quantities of water droplets travelling at high speed and turbulence. The equipment can be fitted to any machine which produces dust and is working on such applications as grinding and polishing machines, automatic sugar weighers, etc. **Prat-Daniel (Stanmore) Ltd., Whitecroft, Nailsworth, Glos.**

BCE 3468 for further information

Dust Valve

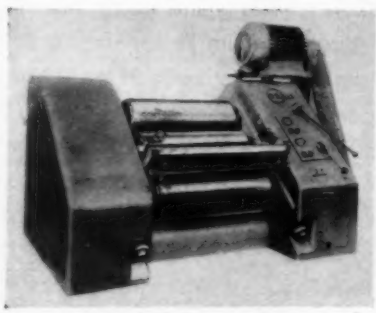
The new Mancuna-Dustex vacuum valve for dust-collector hopper and bin discharges provides, it is stated, an absolute seal. The seal is maintained by negative pressure within the valve, which collapses the flexible Neoprene sleeve. The weight of collected material forces it through the sleeve at a constant rate of flow. **Mancuna Engineering Ltd., Denton, Manchester.**

BCE 3469 for further information

New Foreign Equipment

Hydraulic Homogenising Mill

Draiswerke have introduced a new crush-grinding mill designed for homogenising preparations of high viscosity; in particular, such as those used in paint, printing ink and plastics manufacture. The homogenising rolls are arranged on a slope, the centre roll being supported in stationary bearings while the charge and discharge rolls run in adjustable bearings to which the hydraulic pressure is applied. The sloping arrangement of the rolls provides a low charge level with a relatively high discharge level to aid operation and the smooth flow of material. The cast-iron frame has smooth, simple lines, is of good appearance and simplifies cleaning. All controls are centralised on the right-hand side of the frame. The drive is provided through V-belts and a two-speed gearbox for normal and high-speed operation.



The speeds can be selected while the machine is running. Screw-down pressure, supplied by a static hydraulic system, is controlled by a hand lever. Two models are available, each with an overload capacity of some 40% in the high-speed position. Their power consumption is, respectively 15-40 hp and 18-50 hp. The range is available with mechanical screw-down, but the makers recommend the use of the hydraulic type in view of the ease with which reproducible results are obtained. Pre-selected hydraulic pressures may be incorporated in the processing data. **Draiswerke G.m.b.H., Mannheim, Germany.**

BCE 3470 for further information

Other Items of Interest

A fire-resistant conveyor belt, the Pluvicor, has just been developed by BTR Industries specially for carrying loads on steep gradients. **BTR Industries Ltd., Herga House, Vincent Square, London, S.W.1.**

BCE 3471 for further information

Richards have designed a conveyor-belt driving drum which houses as one unit motor and drive, sealed and oil filled. **Richards Structural Steel Co. Ltd., Phoenix Iron Works, Leicester.**

BCE 3472 for further information

The Geest Tractamatic drive for factory trucks is described as a simple, lightweight, battery-operated reversible free-wheel unit. On withdrawal of the power, the drive automatically disengages, allowing the operator to propel the truck freely by hand. **Geest Industries Ltd., White House Chambers, Spalding, Lincs.**

BCE 3473 for further information

The control equipment of the new Autopak automatic welding equipment consists of components associated with the transformer and which are used to feed and control the welding head. **Rockweld Ltd., Commerce · Way, Croydon, Surrey.**

BCE 3474 for further information

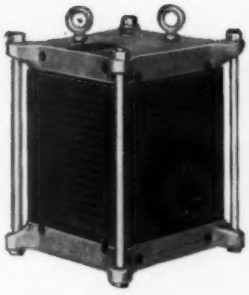
New Materials

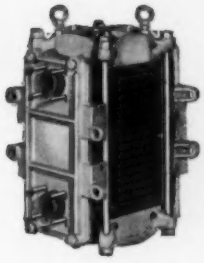
Lucent Products have made available two new plastics—Lucentine, a heat-resistant styrene copolymer which, it is claimed, will completely resist organic solvents, including those which disintegrate ordinary polystyrene; and Polectric SM 11, a new polystyrene-type thermoplastic for high-temperature applications. The softening point of Polectric to B.S. 1493 (1950) is not less than 130°, but the maximum continuous use temperature, for most applications, is not less than 120°C. **Lucent Products Ltd., Oaklands, Clayton Road, Chessington, Surrey.**

BCE 3475 for further information

A new polar synthetic rubber latex, Politone K.745, has been developed at the Dunlop Research Centre. It is described as an oil-resistant copolymer containing butadiene and possessing properties similar to a butadiene-acrylonitrile copolymer of medium acrylonitrile content. The product is expected to be of use in applications where oil resistance and heat ageing are important considerations. It should not be used, however, with certain non-paraffinic solvents such as trichlorethylene. **Dunlop Rubber Co. Ltd., Fort Dunlop, Birmingham, 24.**

BCE 3476 for further information

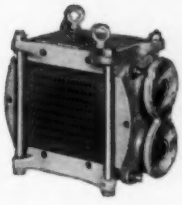




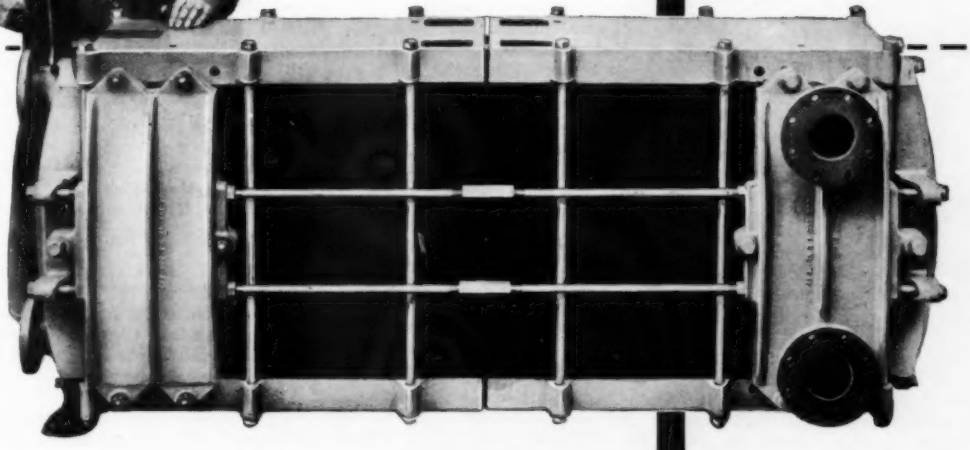
NEW GRAPHITE BLOCK

HEAT EXCHANGERS

New models now provide heat surface areas from 4 sq ft to 200 sq ft



- Twenty models are now available to extend the range of graphite block heat exchangers to suit all corrosive industrial duties.
- All models are suitable for use as heaters, coolers, condensers, or evaporators, involving one or two corrosive fluids and employing single- or multi-pass flow for either fluid.
- All units are designed to provide the accepted graphite block advantages of robustness, compactness, ease of installation and maintenance.
- Tube (hole) dimensions of $\frac{3}{8}$" or $\frac{1}{4}$" or rectangular slots are available to suit heat transfer requirements or industrial scale problems.



POWELL DUFFRYN DELANIUM CARBON & GRAPHITE CARBON PRODUCTS LIMITED

Powell Duffryn
CARBON PRODUCTS LTD

SPRINGFIELD ROAD,
HAYES, MIDDLESEX
PHONE: HAYES 3994

Month's News in Brief

M.V.'s Irradiation Laboratory

Metropolitan-Vickers have built at their Barton works a new irradiation laboratory which will be made available to other firms interested in electron irradiation as an industrial process. The new laboratory, which houses a 4-MeV linear accelerator, was officially opened at the end of May by Mr. H. West, managing director of the A.E.I.-John Thompson Nuclear Energy Company and who has been largely responsible for the setting-up of the new laboratory. The laboratory is a self-contained unit of special construction and interior layout, and provision is made for the efficient handling of a wide variety of products under safe conditions. The whole equipment is controlled from a station outside the accelerator room, and interlocks are fitted to all doors so that the equipment is rendered safe before access to the treatment and accelerator room is possible.

Irish Acetylene Plant

Carbide Industries Ltd., of London (a unit of the Chemical Division of British Oxygen Co.), have recently awarded to W. J. Fraser & Co. Ltd., of Romford, Essex, a contract for the supply and construction of a complete acetylene gas producing plant. The plant is being built under licence from the Shawnigan Chemical Co. of Canada and will be installed in Northern Ireland to provide acetylene to an adjacent factory being built by Du Pont (Great Britain) Ltd. Frasers are also supplying to Du Pont a number of special heat exchangers required for their plant.

German Hydrogen Plant

The chemical plant division of The Power-Gas Corporation Ltd. has obtained an order from Kali-Chemie A.G., Hanover, Germany, for the supply of a Power-Gas/Hercules reforming plant. This unit is based upon liquid hydrocarbon feedstock and comprises a tubular cracking furnace followed by carbon monoxide conversion, carbon dioxide removal and a methanation stage to provide the highest possible purity of the final hydrogen.

Balfour's Research Centre

Work on the new £130,000 Research and Development Centre at Leven, Scotland, for the Balfour Group of Companies has now started. The main objective of this undertaking is to carry out development work for improvement in the design and operation of chemical process plant for many industries, and to widen the application, fabrication techniques and uses of new materials of construction. The new centre will also be available to demonstrate the application of existing designs of plant and process methods to clients' materials, to pioneer new processes and techniques and to carry out work which would not justify the installation of special pilot plant by individual manufacturers themselves.

News Briefs

A new instructional film has recently been added to B.O.C.'s film library. Entitled "The Welding of Lead" (16 mm, black and white, sound, 800 ft; running time 22 minutes), the film is obtainable on free loan from the Photographic Section, British Oxygen Gases Ltd., Sales Technical Service Dept., North Circular Road, London, N.W.2.

A course on the control and instrumentation of reactors is to be held at the Harwell Reactor School from October 6 to 11, 1958. Application forms and further details can be had from The Principal, Reactor School, Atomic Energy Research Establishment, Harwell, Berkshire.

A new instrument company, Research & Control Instruments, has become the sole distributor in the U.K. for the electronic instruments and scientific equipment hitherto marketed by Philips Electrical (Research and Control Instruments Division).

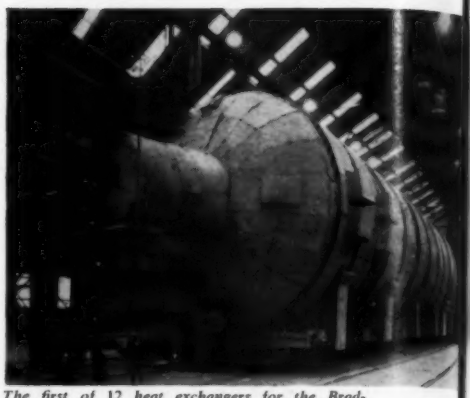
Deionisation (Elga) Ltd. has recently been formed to cover home sales and service of industrial units of Elga Products Ltd. Directors: W. F. Lorch (managing); D. M. Lorch (research); and general manager: K. J. Livett. The ion exchange division of Elga Products Ltd. will in future confine its activities to applications for research, pilot plant and education only.

The name of E. B. Badger & Sons Ltd. is changed to Stone & Webster Engineering Ltd., 20 Red Lion Street, London, W.C.1. Tel.: CHAncery 3366. The name of the company's overseas offices have also been changed, that of the Australian subsidiary to Stone & Webster Engineering Pty. Ltd. The French subsidiary of the company's United States affiliate, Stone & Webster Engineering Corporation, is changing its name to Stone & Webster Engineering S.A., 34 Avenue des Champs Elysées, Paris, 8e. The company's United States affiliate, it is also announced, is forming a new company in the Netherlands to be known as Stone and Webster Engineering N.V., Surinamestraat 34, The Hague.

Vacu-Blast Ltd. have moved into larger premises where offices and works will be combined. The new address is Bath Road, Slough, Bucks. Tel.: Slough 24507-8-9.

The Candy Filter Co. have announced that their chemical pump division will operate as a separate company under the name of Metering Pumps Ltd., at 21 The Mall, Ealing, London, W.5.

Padley & Venables Ltd., specialists in the processing of stainless steel, are moving to new and larger premises at Middlemore Lane West, Aldridge, near Walsall.



The first of 12 heat exchangers for the Bradwell Nuclear Power Station (see page 367) is shown in our picture being stress-relieved at 630°C. Head Wrightson designed and manufactured the exchanger.

Financial News

A pay claim affecting 106,000 workers in the heavy chemicals and 20,000 workers in the drug and fine chemicals section of the industry was tabled during May.

Albright & Wilson Ltd. Net profit for 1957 £1,553,000 after tax. Dividend raised from 18% to 20%. In the first three months of 1958, Group sales and profits have been higher than for the corresponding months of 1957, but not as high as had been hoped for. However, it seems likely that this general pattern will persist for much of 1958.

Pulsometer Engineering Co. Ltd. Net group profit for 1957 £196,395 after tax. Final dividend recommended 15% on Ordinary Share Capital, making a total of 25% for the year. Mr. F. B. Duncan, chairman, although stating that, at the moment, there is a tendency for orders in our industry to be slightly down on former years, said the order book remains good and improved capacity and production facilities will, he believes, because of improved delivery dates, maintain the Company's order position.

Tube Investments Ltd. Interim dividend less income tax at 8s. 6d. in the £ announced. On the 7% Cumulative First Preference Stock and on the 4% Redeemable Cumulative Preference Stock, a dividend at the authorised rate for each class of stock for the half year ending May 31, 1958. On the Ordinary Stock, an interim dividend of 7½% actual on account of the year ending July 31, 1958.

Imperial Chemical Industries have announced a new basis for calculating the annual bonus under its employees' profit-sharing scheme. Present bonus is 1% of an employee's annual earnings for each 1% by which the Ordinary dividend exceeds 5%. The sum available for bonus in any year, in future, will be 22% of the total amount, before tax, paid to all the company's stockholders. As the bonus will automatically change on alteration in total payments to all classes of stockholders instead of with the rate of Ordinary dividend, employees

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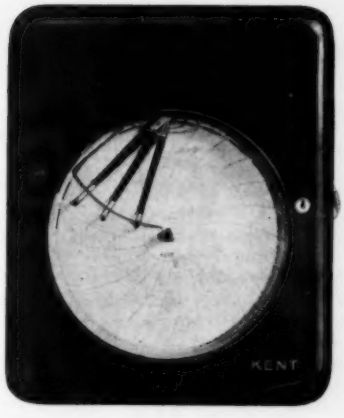
Since it is impossible to indicate the number of combinations and permutations of measurement, function and range possible with *Commander* instruments, please write for brochure, "Commander Class Instruments and Controllers", or telephone Chemical Industry Contracts Dept. (Luton 2440, Ext. 84) for an estimate.



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will benefit by the introduction and extension of all forms of capital which, at present, would not apply.

Gas Purification & Chemical. Interim consolidated statement for the six months to December 31, 1957, shows, before tax, a group deficit of £130,258. After minority interests and writing off subsidiaries' formation expenses, the deficit applicable to the company is £133,322, making a total of £334,655 at December 31, 1957.

Glaxo Laboratories have offered to acquire all the 448,400 Ordinary £1 shares of Allen & Hanbury on the basis of three Glaxo 10s. Ordinary for each Allen & Hanbury Ordinary. This offer, which the directors of Allen & Hanbury unanimously recommend acceptance, is conditional upon 90% acceptance by May 30 or such lower percentage or later date as Glaxo may decide.

Associated Electrical Industries have announced an agreement to purchase the capital of Associated Insulation Products from Elliott-Automation. The purchase price is to be satisfied by the issue of 1,155,555 £1 Ordinary shares of A.E.I. to Elliott-Automation, worth approximately £2¼ million.

D. F. Craig.

People in the News

Mr. D. F. Craig has been appointed to the board of Liquid Systems Ltd., Croydon. Mr. Craig graduated from Sheffield University and in 1945 had the distinction of being the first graduate apprentice at Davey & United Engineering Co. Ltd. He was formerly chief engineer for his present company.

Three new appointments are announced by B.O.C. and are: **Mr. R. C. Hesketh-Jones**, who was formerly sales director (Industrial Division) of British Oxygen Gases Ltd., has been appointed Chief Executive (Overseas) at the company's head office. In this capacity he will handle the overseas affairs of the group in direct association with the managing director, **Mr. T. E. Potts**. **Mr. R. J. Foster**, who has recently been director and general manager of British Oxygen Aro Equipment Ltd., succeeds **Mr. Hesketh-Jones**. **Captain Q. P. Whitford** is taking charge of the Aircraft Equipment Works at Harlow. Captain Whitford previously held a number of Admiralty appointments concerned with equipment and research on electrical and mechanical development projects.

Edgar Allen & Co. Ltd. announce the appointment of **Mr. F. Haigh** as personal assistant to **Mr. B. B. Green**, a director and general sales manager of the company. The appointment of **Mr. I. Somerfield** as home sales manager has also been announced and also that of **Mr. E. Ashurst** to succeed Mr F. Haigh as commercial manager of the Foundry Division.

Mr. John B. Davies, joint sales manager of Lawes Chemical Co. Ltd., has been appointed a director of the company. Mr. Davies joined Lawes as a junior member of the staff in 1944.

Fisher Governor Co. Ltd., of Rochester (a member of the Elliott-Automation Group), announce that **Mr. J. R. Moore** has been appointed a director.

Among the retiring directors re-elected by shareholders at the annual meeting of The International Nickel Co. of Canada Ltd. was **Lord McGowan**, K.B.E., honorary president, Imperial Chemical Industries Ltd.

Dr. W. W. Easton has been appointed principal of the new technical education college centre at Thurso, in Caithness. Engineering apprentices for the Dounreay Atomic Energy Station will study at the college.

Mr. R. L. Elkington, C.B.E., Controller of the Export Licensing Branch, retired on May 25, 1958. **Mr. R. Wood** has been appointed Controller as from that date.

Mr. M. A. E. Hodgson, who was to become technical service and development manager in the new I.C.I. Heavy Organic Chemicals Division, will not take up this appointment, as he has been appointed head of the newly-formed Technical Department at Head Office. The HOC Division appointment is now to be filled by **Mr. J. S. A. Forsyth**, of I.C.I. (New York) Ltd.

Mr. A. J. Prince, development director of the Heavy Organic Chemicals Division, has recently completed 30 years' service with the company. He joined I.C.I. as a chemist in the Billingham Research Department.

Mr. C. M. Vignoles, Mrs. M. Harrison and **Mr. G. D. Mouat** have been appointed members of the Council of Industrial Design. **Mr. D. Dow** has been appointed a member of the Scottish committee of the council.

Tube Investments Ltd. announce that **Mr. A. J. S. Aston** and **Mr. R. D. Young** have been appointed to the board. Both Mr. Aston and Mr. Young have served the group for many years in senior executive capacities.

At the annual general meeting of the Society of Instrument Technology, the Bowen Prize was presented by **Mr. P. Goudime**, president of The Scientific Instrument Manufacturers' Association of Great Britain Ltd., to **S. T. Lunt** for his paper "Process Development and Plant Design—the Role of Instrumentation with Particular Reference to the Application of Computers". The presentation was followed by a presidential address by the president of the Society, Sir Harold Hartley.

Thompson Bros. (Bilston) Ltd., of Bradley Engineering Works, Bilston, Staffs., announce that **Mr. E. E. Pheasey**, M.B.E., M.I.B.E., has been appointed works director.

The Plessey Co. Ltd. announce that **Mr. K. H. Frostick** has recently assumed the responsibilities of sales manager of the company's Chemical and Metallurgical Division at Towcester, Northants.

Obituary

The death of **Major F. H. Bramwell** on May 7 has been announced by The Power-Gas Corporation Ltd. Major Bramwell joined the board of directors of The Power-Gas Corporation Ltd. and Ashmore, Benson, Pease & Co. Ltd. in April, 1949. He spent most of his working life with Imperial Chemical Industries Ltd., the latter part as chief engineer of their General Chemicals Division. He was keenly interested in all technical developments and right up to his death was active in the affairs of civil, mechanical, electrical and chemical engineering institutions, so much so that on the day of his death he was to have taken the chair at the annual luncheon of the British Electrical and Allied Industries Research Association.

Coming Events

Home

June 24. *Institution of Chemical Engineers. Symposium on the Organisation of Chemical Engineering Projects:* At Olympia, London, W.14, **until June 26.**

July 7. *Society of Chemical Industry. Exeter Conference:* At University of Exeter, Devon, **until July 11.**

July 7. *National College of Rubber Technology. Chemical Analysis of Rubbers and Plastics:* At the College, Holloway Road, London, N.7, **until July 18.**

July 17. *Institution of Chemical Engineers: Graduates' and Students' Section Meeting with Science Sixth-Formers:* At the University of Leeds. **10 a.m.**

July 21. *International High-Polymer Conference:* At Nottingham University, **until July 24.**

Overseas

June 17. *International Congress on Metallurgical Research:* At Liége, Belgium, **until June 29.**

June 22. *American Institute of Chemical Engineers. International Meeting and 50 Anniversary:* At Philadelphia, Pa., **until June 27.**

June 23. *Third International Coal Preparation Congress:* At Liége, Belgium, **until June 23.**

June 23. *International Union of Pure and Applied Physics. Colloquium on Physics of Very Low Temperatures:* At Leyden, Netherlands, **until June 28.**

June 30. *International Institute of Welding. Annual Assembly:* At Vienna, Austria, **until July 5.**

June 30. *2 CERN Conference on High Energy Nuclear Physics:* At Geneva, Switzerland, **until July 5.**

July 2. *International Union of Pure and Applied Physics. Colloquium on Magnetism:* At Grenoble, France, **until July 5.**

July 3. *International Academy of Ceramics Congress:* At Ostend, Belgium, **until July 9.**

July 7. *Low Energy Nuclear Interactions and Nuclear Structure:* At Paris, **until July 12.**

July 10. *International Congress of Radiation Research.* National Academy of Sciences—National Research Council, Burlington, Vt., **until July 16.**